water

MDPI

Article

Socio-Economic Aspects of Centralized Wastewater System for Rural Settlement under Conditions of Eastern Poland

Aleksandra Brzusek, Marcin K. Widomski and Anna Musz-Pomorska *

Faculty of Environmental Engineering, Lublin University of Technology, Nadbsytrzycka 40B, 20-618 Lublin, Poland; a.brzusek@pollub.edu.pl (A.B.); m.widomski@pollub.pl (M.K.W.)
* Correspondence: a.musz-pomorska@pollub.pl; Tel.: +48-815-384-481

Abstract: This paper presents a case study concerning multivariate analysis, including social and financial aspects, as well as environmental impacts, of the organized sanitation development under conditions of the selected rural settlement in Poland. Three technologically up-to-date variants of sanitary sewerage network concepts with the different assumed sewage transport, i.e., pressure, pressure-gravity and gravity, were proposed together with the investment and operation and maintenance costs estimation. The willingness-to-accept (WTA) and willingness-to-pay (WTP) survey was used to analyze the level of social acceptance and involvement. The financial analysis covered two economic and cost-efficiency dynamic indicators, benefits–costs ratio (BCR) and dynamic generation cost (DGC), commonly used to support the decision-making process. The environmental aspects were assessed by the possible anthropopressure caused by sewerage leakage and odor emissions. Results of the WTA and WTP survey presented a significant level of acceptance and involvement of the local population to sustain the improved sanitation. The determined values of DGC indicated low cost-efficiency of the gravity system, while obtained values of BCR for all variants and the actual regional sewage fees showed the low profitability of improved sanitation, i.e., BCR < 1.0. All studied sanitation systems were assessed positively due to their environmental impacts. The performed studies showed that, despite the declared willingness to accept the organized sanitation and to pay the sewage fees, the economical sustainability of the proposed designs is doubtful over the longer time duration due to the significant capital and operation costs affecting the sewerage payment value.

Keywords: sustainability; rural sanitation; economic profitability; cost-efficiency; social acceptance

check for updates

Citation: Brzusek, A.; Widomski, M.K.; Musz-Pomorska, A. Socio-Economic Aspects of Centralized Wastewater System for Rural Settlement under Conditions of Eastern Poland. *Water* **2022**, *14*, 1667. https://doi.org/10.3390/w14101667

Academic Editor: José Álvarez-García

Received: 29 April 2022
Accepted: 19 May 2022
Published: 23 May 2022

1. Introduction

1.1. Rural Sanitary Sewage Management and Groundwater Quality

Sustainable development of rural areas requires availability of unpolluted surface water and groundwater resources, as well as clean arable soil [1–3]. Thus, limited freshwater resources endangered by climate changes and anthropopressure should be treated as one of the most important concerns for rural societies. Generally, the negative impacts of rural populations on availability of clean water may be mainly related to the agricultural activity, as well as wastes and excrement management [4–8], allowing possible point or area pollutant migration. According to the recent assessments [9,10], even approx. 4.5–5.6 billion of additional people in the world will require access to sanitation in 2030. Thus, limiting the possibility of soil, surface water and groundwater pollution by the improved sanitary sewage seems to be crucial for sustainability of rural areas [8,11–16], so development of sustainable sewerage management systems seems to be necessary. Moreover, the clear and visible disparities between access to water and sanitation services in urbanized and rural areas were reported in many regions of the world [12,16–21].

Actually, the centralized sanitation in rural areas in Poland, inhabited, due to the official data [22–24], by approximately 15,300,000 people, i.e., 39.5% of total population of Poland, is undeveloped. While 85.3% of rural residents in Poland are recently connected to centralized water supply networks, only 41.3% of them are connected to sanitary sewerage systems. According to the official data, the remaining rural population bases the sanitary wastewater management on the 256,811 domestic, household sanitary wastewater treatment plants (WWTPs), 2,162,662 septic tanks, and wastewater car transport to the 2341 sewage delivery stations of local WWTPs. Unfortunately, the availability of organized sanitary sewage management is not uniform in Poland. Only 23.3% of the rural population in Lublin Voivodship (one of the less developed regions in Poland and in the European Union [17], total population 2,086,403, rural population 1,116,914) is currently connected to the organized systems of sanitary sewage disposal, the length of which is only 32.24% of water supply systems. The remaining rural population of the region uses 28,253 local wastewater treatments plants, 176,357 septic tanks, and 183 sewage delivery stations.

The undeveloped or low-quality local systems of sanitary sewage management and disposal may pose the significant threat to the natural environment, including groundwater, of rural areas affecting the sustainable development of local population due to possible ecological and social problems [20,25,26]. The malfunctioned, leaky septic tanks or faulty on-site sanitation devices were commonly reported as the main source of groundwater pollution [27–32]. In Poland, the official rapport of the Polish Inspectorate of Environmental Protection [33] states that the quality of 22.82% of groundwater resources was assessed as poor, according to Polish legal regulations [34,35]. The main reasons of the decrease in ground water quality were recognized as the insufficient isolation of groundwater from the surface water, disorganized and undeveloped water and sewage management, road and railways traffic, as well as the inappropriate municipal and industrial waste management. Figure 1 presents results of the annual operational groundwater monitoring for sampling points located in rural areas, including rural development, arable lands, meadows, vegetation and forests, provided by The Polish Geological Institute—National Research Institute [36] for period 2010–20, with groundwater quality divided into classes according to [34,35]. The presented monitoring was performed for an annually changed variable number of sampling points, i.e., 241–1060. The range of reported locations with poor groundwater quality varied between 20.6% and 36.6%. The greatest quantity of rural monitoring points was included in the reporting in 2016 and 2019, with 1050 and 1067 points, respectively. For these periods, the cumulative percentage share of groundwater of unsatisfactory and bad quality was 21.3% and 20.6%. The highest observed number of monitoring points with determined unsatisfactory and bad quality of groundwater, i.e., 36.6% of 298 points, was noted in 2011.

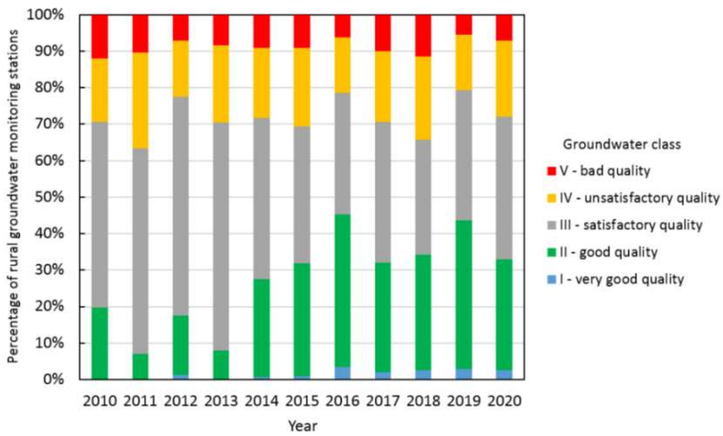

Figure 1. Results of groundwater monitoring quality in rural areas in Poland, period 2010–2020, based on [36], groundwater quality classes according to [34,35].

The presented anthropopressure exerted by rural population activities on groundwater in rural areas may be, in our opinion, reduced by the development of sustainable centralized sanitary wastewater systems or increased popularity of up-to-date, sophisticated and effective on-site wastewater treatment devices (domestic wastewater treatment plants). However, all the proposed design concepts should be carefully studied under the local conditions by the multicriteria method in order to verify their economic, social, environmental, technical and legal sustainability [13,37–43].

1.2. Sustainability of Rural Sanitation

The concept of sustainable sanitation, assuming the safe disposal of human excreta over the long term, takes into consideration issues of human health, affordability, environmental sustainability and institutional appropriateness [4,16,20,44]. Thus, the sustainable rural sanitation systems should be assessed, already at the stage of preliminary conceptual design, according to the public health and environmental impacts, economic profitability and cost-efficiency, as well as the social, institutional and legal aspects [12,40–43,45,46].

Nowadays, in developed countries, application of modern up-to-date materials, technologies, good practices and know-how of sewage transport allows successful significant reduction of sanitary sewage influence on the humans health and quality of the natural environment. However, under conditions of rural settlements, with low population density, low volume of generated sanitary sewage, dispersed housings and unfavorable landform application of rather costly (investment as well as operation and maintenance costs) centralized sewerage systems may be limited by several non-technical factors including financial capacity of the local self-governments and rural population to cover all costs of the investment, social acceptance and involvement of residents in construction, and willingness to pay the regular sewerage fees [47–56]. However, it is worth mentioning, that in several rural regions of undeveloped countries, the technical and reliability aspects of on-site sanitation may be more important than financial [12]. Generally, costs required for successful implementation of sustainable sanitation cover capital expenditures, capital costs, operation and minor maintenance expenditures, capital maintenance expenditures, direct and indirect support expenditures [57]. The sophisticated, spatially large pipeline systems of conventional (gravity) and unconventional (e.g., pressure or vacuum) sewage transport require significant financial loads including materials, earthworks, manpower, energy consumption, environmental fees, servicing, pipelines flushing, etc.—costs which directly affect the value of legally determined sewage tariffs paid by the residents [13,48,49,57–59]. In turn, when combined with the short-term thinking [26], this may negatively affect the willingness of the local rural populations to accept and pay. The social acceptance and willingness to pay presented by the local rural population are crucial to successful implementation of improved sustainable sanitation systems, and may be affected by population income, awareness, concerns, value of water and wastewater services payment, satisfaction of current sanitation service, age, gender, education level, etc. [14,60–62]. Taking into account that under conditions of Poland the sewage payment fees are determined based on the precise estimation of inflows and outflows of the water company [63], and approved by the central governmental office Państwowe Gospodarstwo Wodne Wody Polskie (National Water Holding Polish Waters) [64,65], the social involvement already at the stage of design is necessary. Thus, each separate case of rural improved sanitation design, meeting legal and technical requirements, requires answering, already at the decision-making stage, of several questions concerning its future sustainability: i) which type of sewage transport is the most financially suitable to the local landform, housing spatial development, population density, sewage volume and economic conditions, etc.; ii) what is the level of social awareness influencing willingness to accept the new design; iii) what is the acceptable value of sewage services payment for the local population [13,17,37,40,55,66,67].

This paper presents the case study of multivariate sustainability analysis of three proposed centralized sanitation designs for a rural settlement in Eastern Poland. The presented research was mainly focused on the social and economic aspects of sustainable rural sanitation, but the environmental issues were also introduced. The proposed designs covered up-to-date, technologically modern systems using gravity and pressure pipelines to collect and dispose sanitary sewerage from the households. The performed analyses were based on determined dynamic economic and costs-efficiency indicators, results of the willingness-to-accept and willingness-to-pay survey, and selected indicators of environmental and social impacts. The obtained results provide the better understanding of interdependence of various circles of sustainability, allowing the successful implementation of rural organized sanitation.

2. Materials and Methods

The main aim of this study was to assess the economic, social and environmental sustainability of three technologically up-to-date and reliable systems of rural centralized sanitation systems, under economic and legal conditions of Poland, by the multicriteria method. The general idea of the assumed methodology of research is presented in Figure 2.

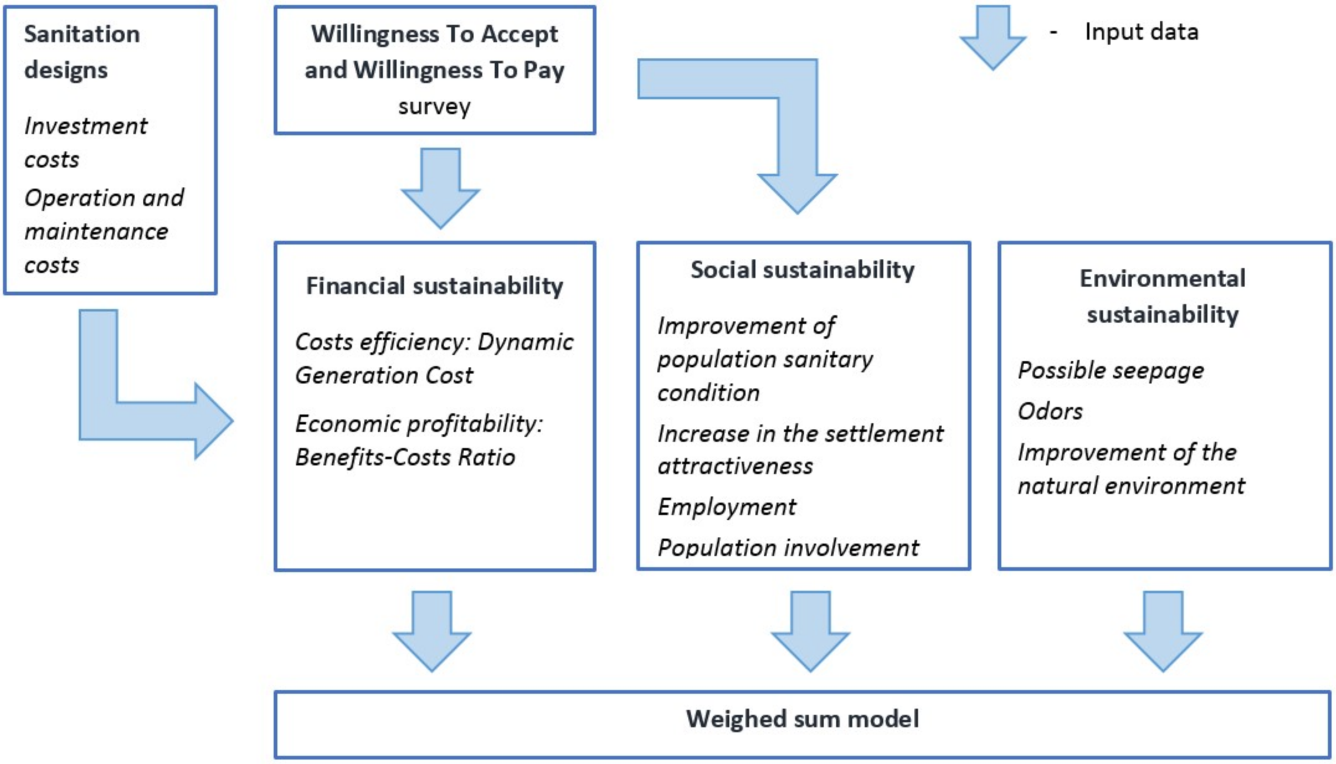

Figure 2. Scheme of assumed methodology of research.

The presented research was divided into two separate parts. During the first phase, the assessment of the willingness-to-accept (WTA) and willingness-to-pay (WTP) level presented by the Zagrody rural population towards the involvement in organized sewerage management was performed. The performed survey allowed not only the assessment of the possible social acceptance and involvement level, but also allowed the input data, e.g., possible acceptable sewage fee, for the financial analysis. The second phase, using data obtained during the first phase, covered the proposal of three conceptual up-to-date designs of sanitary sewage systems for Zagrody, utilizing the existing wastewater treatment plant and determination of their economic, social and environmental characteristics. Thus, two different types of method were applied to assess the socio-financial aspects of organized sanitary sewage management in the Zagrody settlement: the contingent valuation method (CVM) questionnaire and the selected sustainable development indicators of economic and costs efficiency, as well as social and environmental aspects of the proposed designs [21,59,68].

2.1. Object of Study

The rural settlement Zagrody, located in rural Garbów commune, approx. 20 km from Lublin, NW part of Lublin Voivodship, Poland, was selected as the object of this study. The Garbów commune is currently inhabited by approximately 9040 residents living in 2456 households. The organized water supply of 148.5 km length covers 86.5% of the population, delivering 304,400 m^3 of potable water per year. On the other hand, only 17.6% of Garbów population is connected to the centralized sanitary wastewater systems, total length 25.2 km (22.2 km managed by the local authorities), collecting 80,000 m^3 of sewage per year. There are two wastewater treatment plants operational in Garbów, communes. One municipal WWTP in Garbów and one private WWTP in Zagrody, former sugar plant, of the combined daily capacity 650 m^3 or 3352 EP (population equivalent). The domestic sanitary wastewater management for the remaining households (unconnected to sewerage system) is performed by 372 domestic wastewater treatment plants (infiltration drainage) and 1830 septic tanks of uncontrolled sealing quality.

The area of Zagrody settlement, population 1303, is approx. 312 ha. The terrain elevation in Zagrody varies between 175.6 and 193 m above sea level, while groundwater level reaches 7 m below the surface. The dominant soils are loamy sand as well as light, medium and heavy loams. The Zagrody settlement covers 141 single-family houses, 10 multifamily buildings, and a shop. The settlement is equipped with underground water supply and electricity networks. There is no sewerage pipelines network in the Zagrody settlement.

2.2. Designed Rural Sanitation Network Variants

There were assumed three variants of centralized sanitary wastewater management networks in the Zagrody settlement, all utilizing the existing wastewater treatment plant (WWTP) of the required capacity. The proposed variants covered (i) a pressure and gravity system; (ii) a pressure system; and (iii) a conventional gravity system with network pumping stations located in unfavorable terrain conditions. The vacuum sewerage transport system was excluded from our analyses due to high investment and O&M (operation and maintenance) costs, usually greater than in the case of conventional sanitation [59]. All developed variants of sewage management were designed to collect and deliver to WWTP the annual volume of 64,301.3 m^3 (daily approx. 176.17 m^3) of sanitary sewage. The schemes of developed concept variants of a rural sewerage system for the Zagrody settlement are presented in Figure 3. For each assumed variant, the following design steps were performed: (i) spatial pipelines development; (ii) hydraulic calculations with selection of pipelines diameters, pumps, sewage tanks, etc., included; (iii) investment costs estimation; (iv) operation and maintenance (O&M) costs estimation. The determined preliminary investment cost [66] for each studied variant covered fixed assists, including sanitary network materials, equipment and fittings, preparatory and installation works, earthworks, manpower and the other technical costs like designing, supervision and management. The assumed O&M costs included environmental payments, control and servicing, salaries, spare parts and power consumption by network sewage pump stations. All the assumed cost values were based on our previous experience, current pricings and available public data [13,17,69].

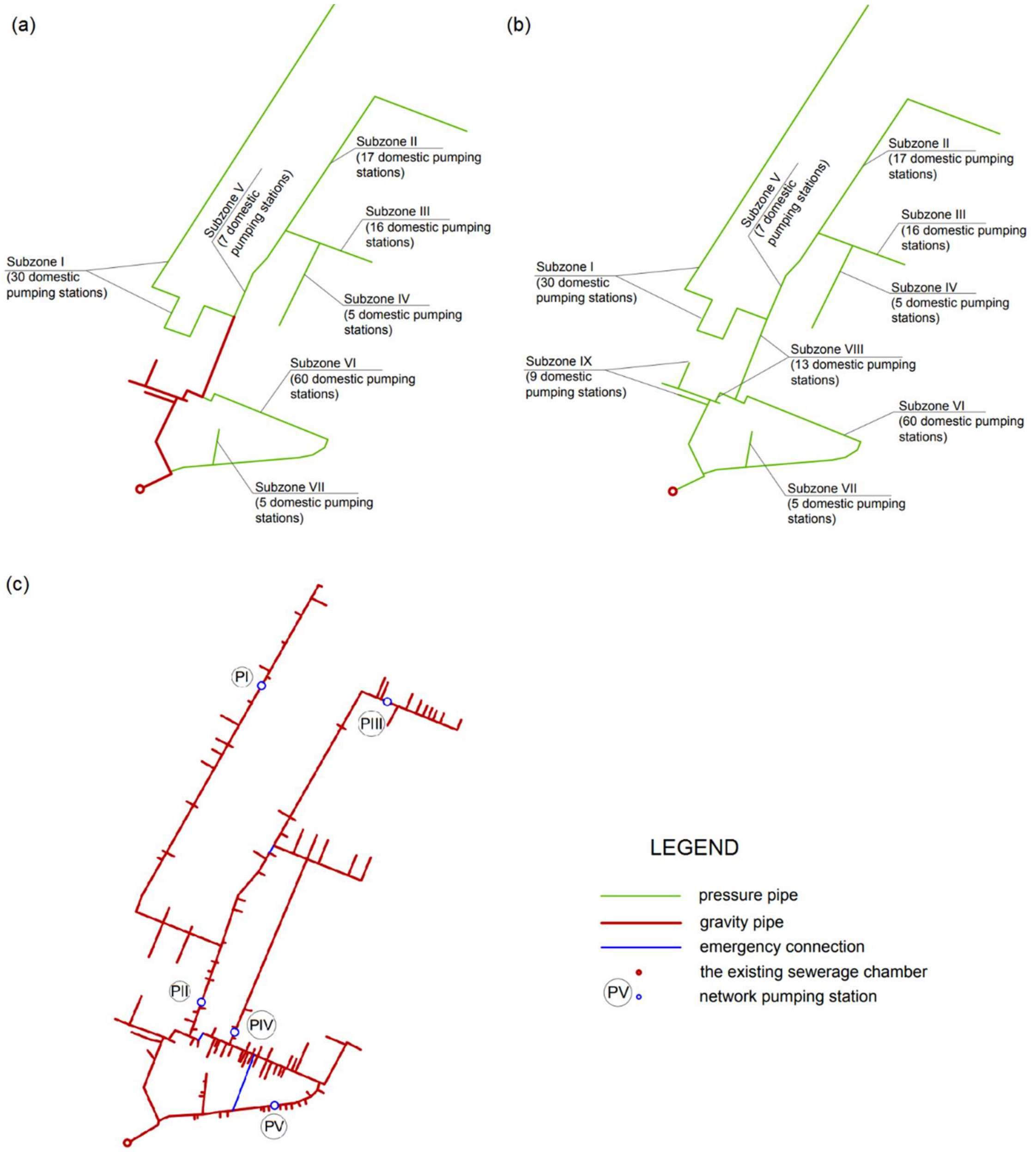

Figure 3. Schemes of developed variants of sewerage system network for the Zagrody settlement: (**a**) Variant I, (**b**) Variant II, (**c**) Variant III.

2.2.1. Variant I

The first assumed variant of centralized sanitary sewerage management in Zagrody covered mixed gravity and pressure pipelines system. The gravity pipelines, of total length 785.9 m (plus 585.8 m of domestic connection), were designed as 200 and 160 mm PVC-U pipes. The crack resistance PE 100 RC pipes were assumed to be installed under the roads. Due to the relatively low computed sewage flow velocity in gravity pipes, 0.2–0.9 m/s, pipeline flushing was assumed. The pressure part of the designed sanitation system covered 4788.3 m of network pipelines, 3224 m of pressure domestic connections, and 130 domestic sewage pumping stations equipped with sewerage pumps Wilo-DrainLift WS1100 (power consumption 1.022–6.297 kW). The pressure pipelines were designed as 63 mm and 90 mm PE 100RC PN10 SDR17 pipes. The domestic sewage pumping stations will be supplied in power via domestic electricity installations.

2.2.2. Variant II

The second concept of organized sanitary wastewater management in Zagrody covered pressure sanitation system consisting of 5744.1 m of pipelines and 3504.7 m domestic connections, diameters 63 mm and 90 mm, PE 100RC PN10 SDR17, supported with 142 domestic sewage pumping stations equipped with sewerage pumps Wilo-DrainLift WS1100. Like in the case of Variant I, the domestic sewage pumping stations will be supplied in power via domestic electricity installations.

2.2.3. Variant III

The third assumed variant of sanitary wastewater management in Zagrody consisted of a gravity sewer with pressure pipelines, applied in areas of unfavorable topography, equipped in five network sewage pumping stations. The designed system covered gravity 200 mm and 250 mm PVC-U and 50 mm PE100RC PN10 SDR17 pressure pipelines. The gravity household connections were assumed as 160 mm PVC-U pipes. The total length of network pipelines is 6220.6 m, while household connections is 3362.63 m. The designed sewage pumping stations were using BS800 Meprozet pumps. The gravity pipeline flushing was assumed due to the relatively low computed value of sewage flow velocity, i.e., 0.15–1.1 m/s.

The comparison of determined preliminary investment costs and assumed annual operation and maintenance costs for all studied variants of organized sanitation is presented in Table 1. The visible differences in investment and O&M costs between Variant III and the remaining designs are mainly related to the assumed technology of sanitary wastewater transport, i.e., the grater diameters of pipelines (in accordance to Polish law [70–72]), greater volume of earthworks, and finally, required flushing of pipelines with unavailable self-purification sewage flow velocity. The observed value of sewage flow velocity inside the pipelines is directly affected by three factors: (i) low volumetric flow rate due to dispersed rural population, (ii) biding statutory regulations in Poland restricting the smallest gravity network pipe diameter as 0.2 m [70–72], and (iii) unfavorable terrain landform, not allowing design with the greater inclination of pipelines. Thus, in the case of low velocity of sewage flow, below the self-purification velocity, the regular flushing of pipelines is required.

Table 1. Assumed preliminary investment and annual O&M (operation and maintenance) costs for each studied variant.

	Total Investment Costs (PLN)	**Annual O&M (PLN)**
Variant I	6,688,394.56	50,599.45
Variant II	6,637,130.90	48,803.20
Variant III	9,949,410.48	58,832.90

Due to the accepted methodology of the study, assuming incorporation of the local community, the WTA and WTP survey, and dynamic changes of currency in 2022, all pricing and costs values will be presented in Polish Złoty (PLN), of which the rough actual exchange rate (April 2022) is 1 euro to 4.7 PLN.

2.3. Methods Description

2.3.1. Contingent Valuation Method (CVM) Questionnaire

The analyses of WTA, WTP and social aspects of the discussed variants of centralized sanitary sewage management in Zagrody was based on the results of the CVM questionnaire distributed through 100 residents of the settlement. The proposed survey also allowed the determination of the required input data for the economic feasibility analysis considering the possible declared value of sewerage fee payment. The questionnaire included two types of questions considering willingness-to-accept (WTA) and willingness-to-pay (WTP), presented in Table 2.

Table 2. WTA (willingness-to-accept) and WTP (willingness-to-pay) questionnaire used in the study.

No.	Question	Possible Choice
1	Are you aware that leaky septic tanks and pouring sewage on the fields affect quality of soil and groundwater?	Yes/no
2	In which manner do you collect and dispose of sanitary sewage in your household?	Septic tank/domestic sewage treatment plant
3	Problems encountered in sewage disposal?	Inconvenient term/no precise appointment possibility/odors/others
4	Are you interested in organized disposal of sanitary sewage?	Yes/no
5	What is the actual cost of 1 m^3 of sewage removal in your household?	5–10 PLN/11–15 PLN/16–20 PLN/21–25 PLN/above 25 PLN
6	Provide frequency of sewage removal from septic tank	Each month/1–2 months/2 months/2–3 months/3 months/3–4 months/4 months/4–5 months/5 months/5–6 months/6 months/over 6 months
7	Provide the maximum sewage fee you willing to pay	2–28PLN
8	Would you be able to pay for 3 years the charge equal to the current costs of sewage disposal (later the lower, standard fee) to allow construction of organized sanitary sewage system?	Yes/no
9	Age	20–25 years/26–30 years/31–35 years/36–40 years/41–45 years/46–50 years/51–55 years/56–60 years/over 60 years
10	Gender	Male/female

2.3.2. Economic Sustainability

The economic sustainability and cost efficiency of the developed concepts of organized sanitary sewage systems in Zagrody were assessed by application of two popular complex dynamic indicators, benefits–costs ratio (BCR) and dynamic generation cost (DGC), allowing long term assessment by taking into account the possible variable value of money during the assumed duration of investment life:

$$BCR = \frac{PV_b}{PV_c} \tag{1}$$

where PV_b—present value of investment benefits (monetary value, PLN), PV_c—present value of investment costs (monetary value, PLN).

$$PV_b = \sum_{t=0}^{N} \frac{CT_{bt}}{(1+i)^t} \tag{2}$$

$$PV_c = \sum_{t=0}^{N} \frac{CT_{ct}}{(1+i)^t} \tag{3}$$

where CT_{bt}—benefits cash flow for a t period (monetary value, PLN), CTc_t—costs cash flow for a t period (monetary value, PLN), N—total number of periods (years), i—discount rate (%).

$$DGC = p_{EE} = \frac{\sum_0^{t=n} \frac{IC_t + EC_t}{(1+i)^t}}{\sum_0^{t=n} \frac{EE_t}{(1+i)^t}} \tag{4}$$

where IC_t—annual investment costs in given year (monetary value, PLN), EC_t—annual exploitation (operation and maintenance) costs in given year (monetary value, PLN), t—year of investment time duration, from 0 to n, where n is the last assessed year of investment activity (year), i—discount rate (%), p_{EE}—price of the ecological unit effect of the investment (monetary value per volume, PLN·m^{-3}), EE_t—annual ecological unit in given year (m^3),

The BCR is a very clear and easy-to-understand indicator of the investment profitability. The neutral investment is characterized by BCR = 1.0. In the case of BCR < 1.0, the investment brings no profits; conversely, investment with BCR > 1.0 is profitable, and brings benefits to the investor. The DGC cost efficiency indicator describes the cost of ecological effect of the investment (in this case one cubic meter of sanitary sewage collected and delivered to WWTP), taking into account investment and O&M costs. Generally, the lower DGC value, the greater the costs efficiency of the investment.

The calculations of both studied indicators were based on the following assumptions: duration of analysis 30 years (typical for water supply and sanitation investments, according to [73]), discount rate 7% (adjusted to the actual economic situation in the region and to the object of analysis [66]), and mean annual volume of sanitary sewerage 64,301.3 m^3/year. The BCR calculations were also based on possible financial benefits of the water company, based on the sewerage fee paid by the population. Four possible scenarios, as a result of the WTA and WTP questionnaire, were tested: (i) option A: actual fee in Garbów commune 6.37 PLN/m^3; (ii) option B: mean regional fee, determined for 20 rural communes from Lublin Voivodship, Poland, 5.69 PLN/m^3; (iii) option C: 14.60 PLN/m^3 mean maximum acceptable fee declared by residents of Zagrody; iv) option D: mixed fee, the maximum mean declared actual fee for sewage management based on septic tanks 17.50 PLN/m^3 for the first three years and 6.37 PLN/m^3 actual fee for the remaining duration of the analysis period. Additionally, the value of sewage fee per cubic meter and level of required outside founding for which investment is neutral, i.e., BCR = 1.0, were determined for each studied variant.

2.3.3. Social and Environmental Sustainability

The following environmental and social issues, determined with the standard SDIs (Sustainable Development Indicators) [40,74,75], were included in our analyses: possible seepage to and from the sewerage system, odors, improvement of the natural environment, improvement of population sanitary condition, increase in the settlement attractiveness, employment, and population involvement. In each criterion the number of points, from 1 to 3, was assigned to allow selection of the most appropriate design (3 points—the best design, 1 point—the weakest design).

2.3.4. Weighed Sum Model

Finally, the developed concepts of organized rural sanitary system for the Zagrody settlement were assessed by the weighed sum model (WSM) due to the possible social, environmental, financial and economic aspects. The assignment of weight factors for each studied criterion (see Table 3) was based on our previous experience, local conditions and literature studies [5,13,76].

$$PC_j = \sum_{i=1}^{n} PI_{ji} w_{ji} \tag{5}$$

where PC_j—performance value of j criterion; n—number of indicators included in the criterion; PI_{ji}—performance value of indicator in the criterion; w_{ij}—weight factor of the indicator in the criterion.

Table 3. Assumed weight factors for economic, environmental and social criterion of assessment.

Criterion	Weight Factor (%)
Economic	50
Environmental	20
Social	30
Sum	100

3. Results

Figures 4–6 present results of the contingent valuation method (CVM) questionnaire containing WTA questions, allowing the assessment of the environmental and economic awareness of the studied local society. As it is visible in Figure 4a, nearly all questioned residents of Zagrody were aware of the significant threat posed by unmanaged sanitary sewage for soil and groundwater. Figure 4b shows that the actual sanitary sewage management is being permed by septic tanks in the majority of respondents, i.e., 95%. The most frequently recognized disadvantages of the actual sewage management were related to sewage transport from households to the wastewater treatment plant, i.e., inconvenient time of wagon arrival and lacking possibility of a precise, convenient appointment for the householders, in sum 89% of responses (see Figure 4c). Only the remaining 11% of responses mentioned odors as the significant disadvantage. Additionally, most of the responders reported quite significant cost of removal of 1 m^3 of sewage (77% of questioned population), 16–25 PLN (approx. 3–5 euro), and quite frequent sewage disposal from the tanks by sewage trucks, i.e., between 2 and 3 months (i.e., 78% of respondents) (see Figure 4e,f). Thus, the results presented above show that the actual manner of sewage management and disposal is generally unsatisfactory for the majority of Zagrody residents due to significant costs and weak, inconvenient organization. This is clearly reflected in the declared willingness to accept the organized system of sanitary sewage management presented by 96% of questioned residents (see Figure 4d).

Figure 5 shows the reported measures of willingness-to-pay for a centralized sewage system presented by the questioned residents of Zagrody. It is visible (Figure 5a) that 74% of respondents would be ready to accept the sewage fee from range 14–20 PLN (approx. 3–4.5 euro) per cubic meter, significantly higher than the actual value of payment in the Garbów commune (6.37 PLN/m^3), or the mean fee value determined for 20 rural communes in the region (5.69 PLN/m^3). Thus, in our opinion, these results again show that the actual individual sewage management is unsatisfactory and inconvenient for the local population. Most of the questioned residents, i.e., 87%, admitted that they are ready to pay a combined fee, three years of the actual pricing for their individual management, and after this period, the standard fee of Garbów commune (see Figure 4b). The readiness to pay for development and operation of organized sanitary sewage disposal among the residents of Zagrody is clearly visible. Figure 6 shows data concerning age and gender of the respondents. Both genders were represented equally among the responders and the questioned group of householders contains mostly people in productive age, which may favor the social acceptance of the organized sewage system.

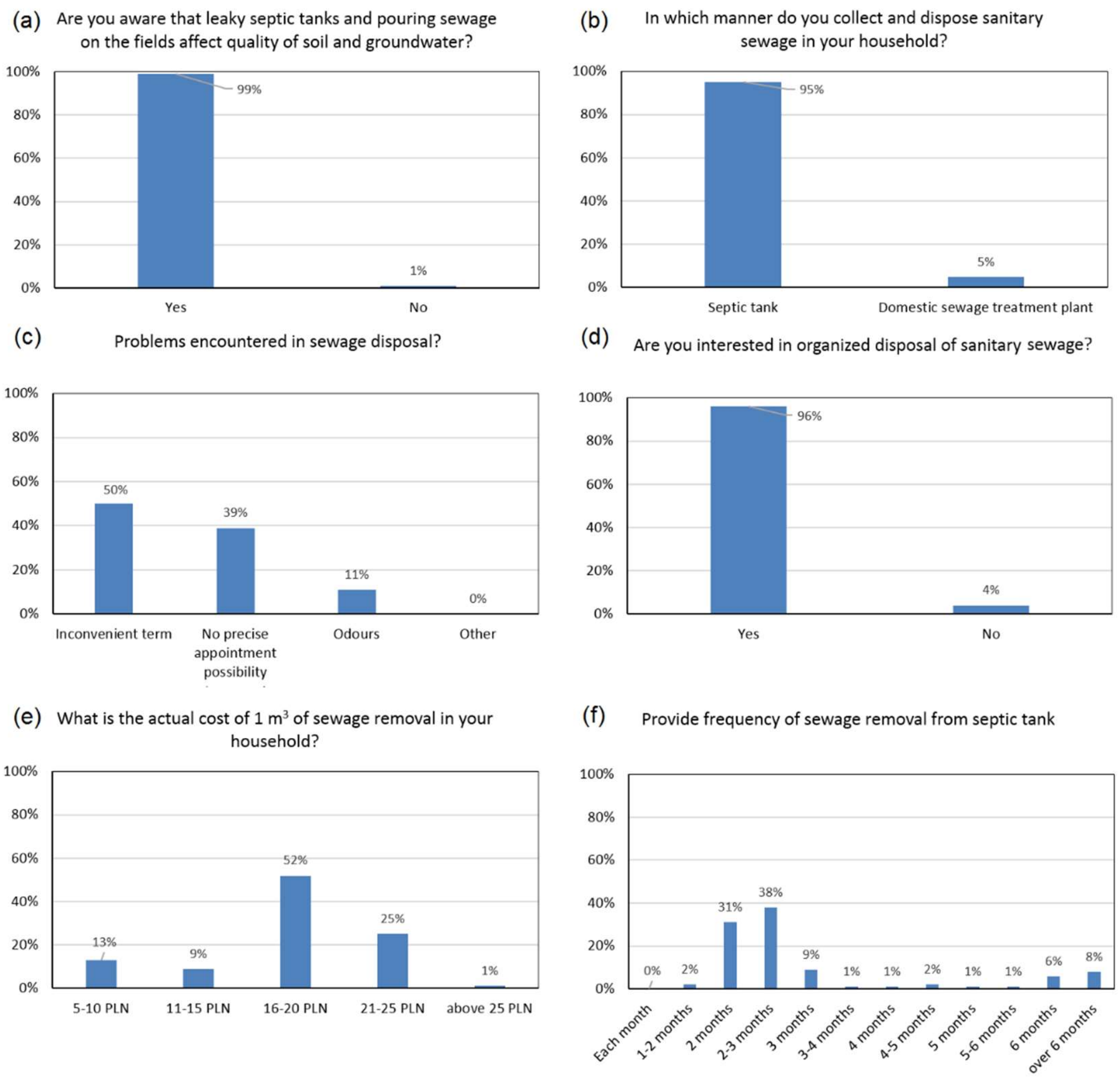

Figure 4. Results of willingness-to-accept questions.

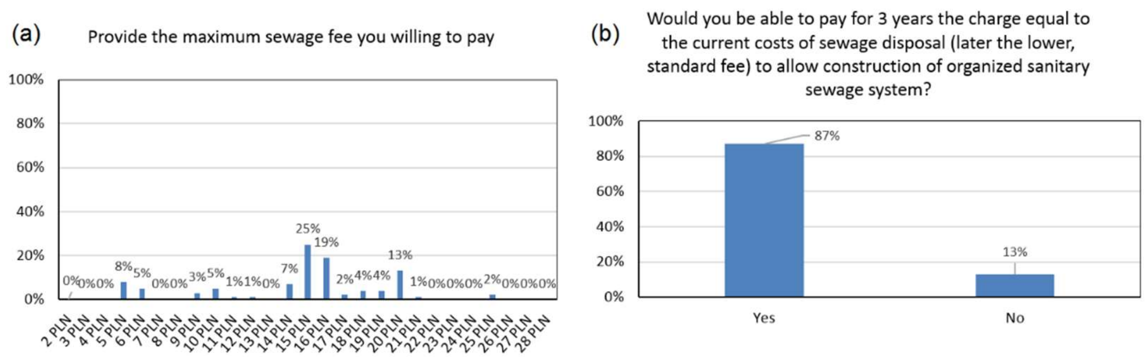

Figure 5. Results of willingness-to-pay questions.

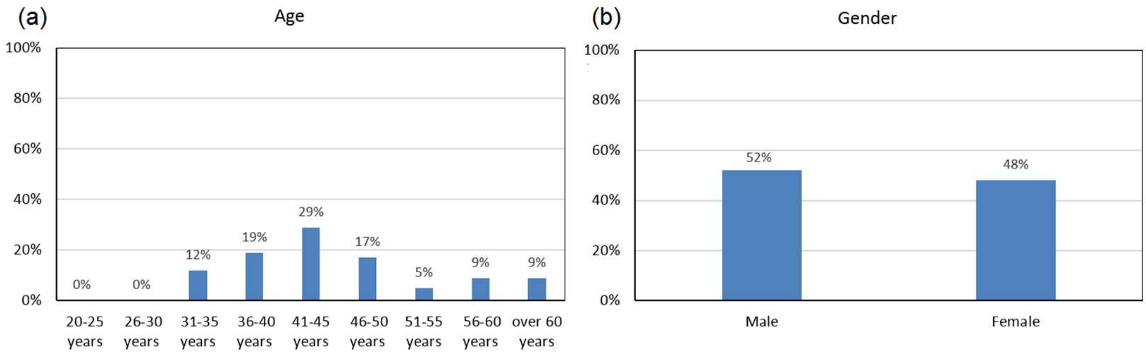

Figure 6. General population data of the WTA and WTP survey: (**a**) respondent age, (**b**) respondent gender.

Figure 7 shows determined values of the dynamic generation costs indicator for three studied variants of organized sanitary sewage disposal in Zagrody. The highest cost efficiency was determined for Variant III for each the discounted cost of ecological effect, i.e., 1 m^3 of collected and transported sanitary sewage, was the lowest. The highest value of DGC, i.e., the highest value of environmental effect costs and the lowest cost-efficiency, was calculated for Variant III of organized sewage disposal, the gravity sewer with pressure pipelines and network pumping stations.

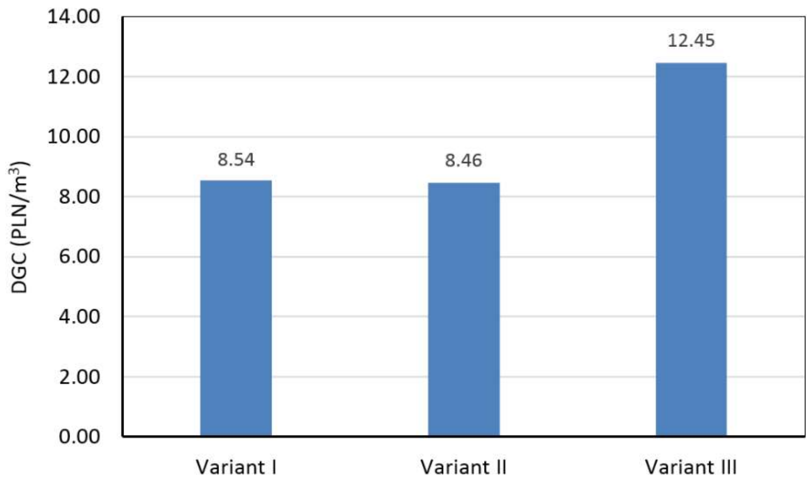

Figure 7. Determined values of dynamic generation cost indicator for three studied variants of organized sewerage disposal in Zagrody.

The analysis of economic profitability, understood as the relation of discounted incomes to discounted costs, i.e., the benefits–costs ratio indicator, is presented in Figure 8, where the determined values of BGC for all three tested variants and for four applied scenarios of possible values of sewage fee per 1 m^3 paid by the residents. It is visible that under the actual conditions, with the current level of sewage fee paid by residents of the Garbów commune (see BCR A in Figure 8), all studied variants of organized sewage disposal are unprofitable, and the assumed benefits are clearly lower than the required investment and O&M costs. The same situation was observed for the second scenario, assuming the mean regional monthly sewage disposal fee. All studied variants of sanitation in this case (see BCR B in Figure 8) would generate financial losses to the local water and sewage enterprise.

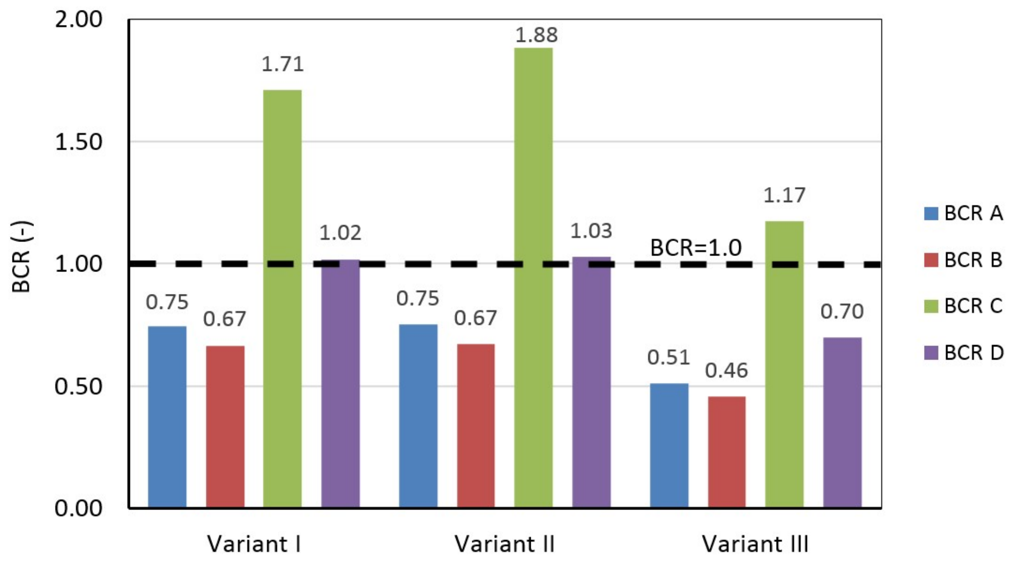

Figure 8. Calculated values of BCR (benefits–costs ratio) indicator for all designed variants of sanitation network and various scenarios of assumed sewage fee payment, BCR = 1.0, threshold of profitability.

The two remaining scenarios, BCR C and BCR D in Figure 8, directly based on the result of WTP survey, allowing assessment of the acceptable level of sewage fee per 1 cubic meter, present acceptable profitability in most cases. Application of the 14.60 PLN/m^3 mean maximum acceptable fee declared by residents of Zagrody allowed BCR values greater than 1.0 (1.17–1.88) to be reached for all tested variants; however, in this case, the financial burden is obvious, since the payment would be approx. 2.3 times higher than in the case of the existing sanitation in the Garbów commune. The last tested option, BCR D in Figure 8, assuming the mixed fee value (actual fee for sewage management based on septic tanks for the first three years and the actual fee for the remaining duration of analysis period) allowed the profitability threshold to be exceeded, i.e., BCR > 1.0, for Variants I and II, based mainly or solely on a pressure sanitation system. In this scenario, the gravity sewers with some network pumping stations reached a BCR value of 0.70, clearly lower than 1.0.

Moreover, the minimal value of sanitary sewage fee for BCR = 1.0, allowing the neutral profitability of the investment during the assumed duration to be secured, would be equal to the DGC value, i.e., 8.54, 8.46 and 12.45 PLN/m^3. The determined required value of outside, governmental or commonwealth, investment costs founding allowing BCR = 1.0 for scenario A (the actual sewage payment in Garbów commune, 6.37 PLN/m^3) was 28%, 27.1% and 53% of capital investment costs for Variants I, II and III, respectively.

Tables 4–6 present assigned preference points in economic, environmental and social criteria of the tested sanitation sustainability. In Table 5, showing assessment of environmental sustainability, the assigned performance points in the category "Odors" was based on odor emissions from the variable sewerage systems reported in the literature [77–80], where a pressure system was assessed as being of the highest emissions. In the same table, the maximum possible point values were assigned to "Improvement of the natural environment" for all developed sanitation variants due to the same obtained ecological effect of sanitation introduction.

Table 4. Results of centralized sewage management economic sustainability assessment, 3 points—the best option, 1 point—the weakest option.

	DGC	BCR A	BCR B	BCR C	BCR D	Sum
Variant I	2	2	2	2	2	10
Variant II	3	3	3	3	3	15
Variant III	1	1	1	1	1	5

Table 5. Results of centralized sewage management environmental sustainability assessment, 3 points—the best option, 1 point—the weakest option.

	Sewage Infiltration	Sewage Seepage	Odors	Improvement of Natural Environment	Sum
Variant I	2	2	2	3	9
Variant II	3	3	1	3	10
Variant III	1	1	3	3	8

Table 6. Results of centralized sewage management social sustainability assessment, 3 points—the best option, 1 point—the weakest option.

	Improvement in Sanitary Conditions	Increase in Settlement Attractiveness	Employment	Population Involvement	Sum
Variant I	3	3	2	2	10
Variant II	3	3	3	3	12
Variant III	3	3	1	1	8

Table 7 presents the final assessment of the studied sewerage disposal systems variants in fields of economic, environmental and social aspects of sustainability, together with the determined final values of the weighed sum model. Thus, it is visible that Variant II of organized sanitary wastewater collection and disposal, as gaining the maximal result of WSM, would be the most appropriate for the actual conditions of the studied rural settlement.

Table 7. Weighed sum model (WSM) results for tested variants of centralized rural sewage management, underlined for the most optimal design.

	Economic Assessment	Environmental Assessment	Social Assessment	WSM
Variant I	10	9	10	9.8
Variant II	15	10	12	<u>13.1</u>
Variant III	5	8	8	6.5

4. Discussion

The performed willingness-to-accept and willingness-to-pay survey showed significant awareness of local population in the aspect of sewerage management and its readiness to sustain the costs of organized sanitation, even in the case of elevated sewage payment. According to the literature, such attitude may be related to developed countries with educated, productive and aware population, where knowledge about environmental impacts of human wastes is available. In such cases, the household income and financial concerns are not limiting the possible economic sustainability of the sewerage system [14,55–57]. Thus, the several important social criteria required for successful sustainable improved sanitation presented by [16,20,40,81,82] were met.

The presented calculations of ecological effect cost, determined by the dynamic generation cost indicator value, for the selected different types of sewerage transport systems are with agreement with the previous reports [13,70,83–85] concerning applicability of gravity sewers under conditions of rural settlements with low population and sparse housing development. In this case, the determined value of ecological effect cost depends clearly on the selected type of sewerage system, which requires a significant volume of earthworks, greater pipeline diameters and possible pipeline flushing. This observation is in agreement with the classification of urban sanitation costs reported by Daudey [57], suggesting that type of selected technology, labor, materials and utility costs and population density are the most dominant factors affecting the total costs, significantly in the case of gravity systems.

The performed analysis of economic profitability (economic feasibility) of the three proposed modern and up-to-date concept designs of sanitation systems for Zagrody showed their limited profitability under local conditions of the studied rural settlement. Generally, the obtained results are in agreement with reports suggesting that the rural sewerage systems, due to the low rural population density, sparse household development, limited volume of sanitary sewage, restricted diameters of gravity pipelines, etc., are hard to implement and operate [25,59,70–72,85,86]; especially if their high investment and O&M cost, affecting the administrative sewage fees directly, are under consideration [63]. Thus, the gravity variant, supported with network pumping stations in locations of the unfavorable terrain development, proposed in this study, presented significant unprofitability, which may result in the low level of public acceptance and willingness to pay. The profitability threshold for this variant was reached only for a very high sewage fee, more than two times higher than the regional fee. Unfortunately, the two other proposed variants, based on pressure system and domestic (household) sewage pumping stations, were also determined as unprofitable for the actual, commune and mean regional fees per 1 cubic meter of sanitary wastewater disposal. The profitability threshold, allowing the generation of incomes for the local self-governmental sewage company operating the system, was reached only in scenarios of elevated fees, BCR C and BCR D, respectively. Thus, our studies show that in the case of the discussed rural settlement, the full social acceptance combined with the significant willingness to pay were necessary to assure profitability of sanitation investment, even at the minimal level (scenario D). Taking scenario C into consideration, with declared mean maximum payment per 1 m^3 of sewage, assuring profitability for all presented sanitation system designs, in the long perspective, the continuation of sewerage operation under such conditions seems to be unlikely, due to the significant financial burden of the local population.

We determined in this case study that the most suitable variant of sanitation for the tested rural settlement offered the highest profitability (for selected variants of sewerage payment acceptable by the local population) for the investor (local water supply and sewage removal company), the best costs efficiency (also due to electric energy used by domestic, household sewage pumping stations payment by the householders), and satisfactory social and environmental aspects. This choice may be generally compared to systems selected for similar locations in many regions in developed or developing countries [13,69,76,86–88].

5. Conclusions

The presented case study covering the selection of the most appropriate organized sanitation system for a selected rural settlement in Eastern Poland, based on the economic, social and environmental indicators of sustainability, allowed us to put forward the following conclusions:

- The successful design, construction, operation and maintenance of the sustainable organized sanitary sewerage system in rural settlements is a rather difficult task. Modern and up-to-date, technologically sophisticated sanitation systems limiting the anthropopressure on the environment are characterized by the significant investment and O&M costs, which may limit their profitability for the local communities.
- All studied improved sanitation designs for the selected low population density rural settlement showed unsatisfactory economic feasibility, with BCR < 1.0, for the actual variants of sewage payment. The economic profitability was possible only after the significant increase in sewage fee.

- Low economic profitability resulting in high sewerage tariff payments may directly affect sustainability of the design, limiting its social acceptance and reducing the willingness to pay.
- Low economic feasibility of the proposed variants of improved sanitation for rural settlement requires outside funding to meet the neutral profitability of the investment, i.e., BCR = 1.0. The required co-funding for pressure and gravity systems reached the level of 27.1–28% and 53% of capital investment costs, respectively.
- Our study showed that social involvement, understood as local population willingness to accept and to pay, is required for reaching the limit of profitability for the water and sewage company. It was impossible to design an up-to-date and profitable system for the studied rural settlement without the increase in sewage payment above the local standards.
- Thus, the willingness-to-accept and willingness-to-pay survey should be, in our opinion, the first step of sustainable sanitation designing, allowing determination of the possible financial involvement of the future users of the system.
- Cost-efficiency of the designed sanitary sewerage network was highly related to the selected system of sewage transport. The increased cost-efficiency was possible in pressure systems (DGC = 8.46–8.54 PLN/m^3), in relation to the gravity one (DGC = 12.45 PLN/m^3), due to smaller pipeline diameters, smaller depth and volume of excavations and earthworks, lack of pipeline flushing necessity, and connecting the household sewage pumping stations directly to the domestic electrical installation.
- The presented method of decision-making support, in our opinion, is universal and may be successfully applied under different local conditions, as fully compatible with the paradigms of sustainable development and all its pillars: environmental, social, economic, technical and legal.
- Our studies are planned to be continued for the different case studies of sustainable rural sanitation in Poland to determine the guidelines for sewage system selection considering the actual economic conditions, settlement size, population density, sewage volume, housing spatial development, etc.

Author Contributions: Conceptualization, M.K.W.; methodology, A.B., M.K.W. and A.M.-P.; software, A.B., M.K.W. and A.M.-P.; validation, A.B., M.K.W. and A.M.-P.; formal analysis, M.K.W.; investigation, A.B. and M.K.W.; resources, A.B. and M.K.W.; writing—original draft preparation, M.K.W. and A.M.-P.; writing—review and editing, M.K.W. and A.M.-P.; visualization, M.K.W. and A.M.-P.; supervision, M.K.W. and A.M.-P. All authors have read and agreed to the published version of the manuscript.

Funding: This research was funded by internal projects of Lublin University of Technology, Poland numbers FD-20/IS-6/024 and FD-20/IS-6/039.

Institutional Review Board Statement: Not applicable.

Informed Consent Statement: Not applicable.

Data Availability Statement: Not applicable.

Conflicts of Interest: The authors declare no conflict of interest.

References

1. Velis, M.; Conti, K.I.; Biermann, F. Groundwater and human development: Synergies and trade-offs within the context of the sustainable development goals. *Sustain. Sci.* **2017**, *12*, 1007–1017. [CrossRef] [PubMed]
2. Howard, G.; Calow, R.; Macdonald, A.; Bartram, J. Climate change and water and sanitation: Likely impacts and emerging trends for action. *Annu. Rev. Environ. Resour.* **2016**, *41*, 253–276. [CrossRef]
3. Guppy, L.; Uyttendaele, P.; Villholth, K.G.; Smakhtin, V. *Groundwater and Sustainable Development Goals: Analysis of Interlinkages*; UNU-INWEH Report Series, Issue 04; United Nations University Institute for Water; Environment and Health: Hamilton, ON, Canada, 2018. Available online: https://cgspace.cgiar.org/handle/10568/98576 (accessed on 28 April 2022).
4. Chinyama, A.; Chipato, P.T.; Mangore, E. Sustainable sanitation systems for low income urban areas—A case of city of Bulawayo, Zimbabwe. *Phys. Chem. Earth* **2012**, *50–52*, 233–238. [CrossRef]

5. Benzerra, A.; Cherrared, M.; Chocat, B.; Cherqui, F.; Zekiok, T. Decision support for sustainable urban drainage system management: A case study of Jijel, Algieria. *J. Environ. Manag.* **2012**, *101*, 46–53. [CrossRef] [PubMed]
6. Istenic, D.; Bodík, I.; Bulc, T. Status of decentralised wastewater treatment systems and barriers for implementation of nature-based systems in central and eastern Europe. *Environ. Sci. Pollut. Res.* **2015**, *22*, 12879–12884. [CrossRef]
7. Pryszcz, M.; Mrowiec, B.M. Operation of the household sewage treatment plants in Poland. *Ecol. Eng.* **2015**, *41*, 133–141. [CrossRef]
8. Piasecki, A. Water and Sewage Management Issues in Rural Poland. *Water* **2019**, *11*, 625. [CrossRef]
9. UNDESA. *World Urbanization Prospects: The 2015 Revision—Volume I: Comprehensive Tables*; Report No. ST/ESA/SER.A/379; United Nations Department of Economic and Social Affairs, Population Division: New York, NY, USA, 2015.
10. WHO/UNICEF. *Progress on Drinking Water, Sanitation and Hygiene: 2017 Update and SDG Baselines*; World Health Organization: Geneva, Switzerland, 2017.
11. Mariolakos, I. Water resources management in the framework of sustainable development. *Desalination* **2007**, *203*, 147–151. [CrossRef]
12. Peter, G.; Nkambule, S.E. Factors affecting sustainability of rural water schemes in Swaziland. *Phys. Chem. Earth* **2012**, *50–52*, 196–204. [CrossRef]
13. Lewicka, A.; Widomski, M.K.; Łagód, G. Economic analyses in sewage system designing for rural settlements—Case study. *Archit. Civ. Eng. Environ.* **2016**, *2*, 145–152. [CrossRef]
14. Byambadorj, A.; Lee, H.S. Household Willingness to Pay for Wastewater Treatment and Water Supply System Improvement in a Ger Area in Ulaanbaatar City, Mongolia. *Water* **2019**, *11*, 1856. [CrossRef]
15. WHO/UNICEF. Joint Monitoring Programme. *Improved and Unimproved Water and Sanitation Facilities*. 7 June 2016. Available online: http://www.wssinfo.org/definitions-methods/watsan-categories/ (accessed on 1 April 2022).
16. Hutton, G.; Chase, C. The Knowledge Base for Achieving the Sustainable Development Goal Targets on Water Supply, Sanitation and Hygiene. *Int. J. Environ. Res. Public Health* **2016**, *13*, 536. [CrossRef]
17. Widomski, M.; Gleń, P.; Łagód, G.; Jaromin-Gleń, K. Sustainable Development of One of the Poorest Province of the European Union: Lublin Voivodeship, Poland—Attempt of Assessment. *Probl. Ekorozw. -Probl. Sustain. Dev.* **2015**, *10*, 137–149. Available online: https://ssrn.com/abstract=2660792 (accessed on 1 April 2022).
18. GWP CEE. *Regional Study Natural Processes of Wastewater Treatment—Actual Status in CEE Countries*; GWP CEE: Bratislava, Slovakia, 2012.
19. Nansubuga, I.; Banadda, N.; Verstraete, W.; Rabaey, K. A review of sustainable sanitation systems in Africa. *Rev. Environ. Sci. Biotechnol.* **2016**, *15*, 465–478. [CrossRef]
20. Pereira, M.A.; Marques, R.C. Sustainable water and sanitation for all: Are we there yet? *Water Res.* **2021**, *207*, 117765. [CrossRef] [PubMed]
21. Isunju, B.; Schwartz, K.; Schouten, M.A.; Johnson, W.P.; van Dijk, M.P. Socio-economic aspects of improved sanitation in slums: A review. *Public Health* **2011**, *125*, 368–376. [CrossRef]
22. GUS. Available online: https://stat.gov.pl/ (accessed on 28 April 2022).
23. BDL Temat. Available online: https://bdl.stat.gov.pl/BDL/dane/podgrup/temat (accessed on 28 April 2022).
24. BDL Tablica. Available online: https://bdl.stat.gov.pl/BDL/dane/podgrup/tablica (accessed on 28 April 2022).
25. Hu, M.; Fan, B.; Wang, H.; Qu, B.; Zhu, S. Constructing the ecological sanitation: A review on technology and methods. *J. Clean. Prod.* **2016**, *125*, 1–21. [CrossRef]
26. Pujari, P.R.; Padmakar, C.; Labhasetwar, P.K.; Mahore, P.; Ganguly, A.K. Assessment of the impact of on-site sanitation systems on groundwater pollution in two diverse geological settings—A case study from India. *Environ. Monit. Assess.* **2012**, *184*, 251–263. [CrossRef]
27. US EPA. *National Water Quality Inventory: Report to Congress*; EPA 305(b) Report; US EPA: Washington, DC, USA, 1988.
28. Engin, G.O.; Demir, I. Cost analysis of alternative methods for wastewater handling in small communities. *J. Environ. Manag.* **2006**, *79*, 357–363. [CrossRef]
29. Edokpayi, J.N.; Odiyo, J.O.; Durowoju, O.S. Impact of Wastewater on Surface Water Quality in Developing Countries: A Case Study of South Africa. In *Water Qualit*; Tutu, H., Ed.; InTech: London, UK, 2017; Chapter 18; pp. 401–416. [CrossRef]
30. Shivendra, B.T.; Ramaraju, H.K. Impact of Onsite Sanitation System on Groundwater in Different Geological Settings of Peri Urban Areas. *Aquat. Procedia* **2015**, *4*, 1162–1172. [CrossRef]
31. Megha, P.; Kavya, P.; Murugan, S.; Harikumar, P. Sanitation Mapping of Groundwater Contamination in a Rural Village of India. *J. Environ. Prot. Sci.* **2015**, *6*, 34–44. [CrossRef]
32. Chuah, C.J.; Ziegler, A.D. Temporal Variability of Faecal Contamination from On-Site Sanitation Systems in the Groundwater of Northern Thailand. *Environ. Manag.* **2018**, *61*, 939–953. [CrossRef] [PubMed]
33. Wiech, A.K.; Marciniewicz-Mykieta, M.; Toczko, B. (Eds.) *Stan Środowiska w Polsce*; Raport; Biblioteka Monitoringu Środowiska: Warszawa, Poland, 2018.
34. Dz.U. 2016, poz. 85. Rozporządzenie Ministra Środowiska z Dnia 21 Grudnia 2015 r. w Sprawie Kryteriów i Sposobu Oceny Stanu Jednolitych Części Wód Podziemnych. (In Polish). Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20160000085 (accessed on 28 April 2022).

35. 35. Dz.U. 2019 poz. 2148. Rozporządzenie Ministra Gospodarki Morskiej i Żeglugi Śródlądowej z Dnia 11 Października 2019 r. w Sprawie Kryteriów i Sposobu Oceny Stanu Jednolitych Części Wód Podziemnych. (In Polish). Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20190002148 (accessed on 28 April 2022).
36. Wyniki badań - 2020. Available online: https://mjwp.gios.gov.pl/wyniki-badan/wyniki-badan-2020.html (accessed on 28 April 2022).
37. Kundziewicz, A.; Miłaszewski, R. Costs-effectiveness analysis of individual wastewater disposal and treatment systems. *Ecol. Eng.* **2011**, *24*, 174–183.
38. Harding, R. Ecologically sustainable development: Origins, implementation and challenge. *Desalination* **2006**, *187*, 229–239. [CrossRef]
39. Harris, J.M.; Wise, T.A.; Gallagher, K.P.; Goodwin, N.R. *A Survey of Sustainable Development: Social and Economic Dimensions*; Island Press: London, UK, 2001.
40. Marques, R.C.; Nuno da Cruz, N.; Pires, J. Measuring the sustainability of urban water services. *Environ. Sci. Policy* **2015**, *54*, 142–151. [CrossRef]
41. Foxon, T.J.; McIlkenny, G.; Gilmour, D.; Oltean-Dumbrava, C.; Souter, N.; Ashley, R.; Butler, D.; Pearson, P.; Jowitt, P.; Moir, J. Sustainability criteria for decision support in the UK water industry. *J. Environ. Plan. Manag.* **2002**, *45*, 285–301. [CrossRef]
42. Balkema, A.; Preisig, H.; Otterpohl, R.; Lambert, F. Indicators for the sustainability assessment of wastewater treatment systems. *Urban Water* **2002**, *4*, 153–161. [CrossRef]
43. Hellström, D.; Jeppsson, U.; Kärrman, E. A framework for systems analysis of sustainable urban water management. *Environ. Impact Assess.* **2000**, *20*, 311–321. [CrossRef]
44. Mara, D.; Drangert, J.; Anh, N.; Tonderski, A.; Gulyas, H.; Tonderski, K. Selection of sustainable sanitation arrangements. *Water Policy* **2007**, *9*, 305–318. [CrossRef]
45. Seleman, A.; Bhat, M.V. Multi-criteria assessment of sanitation technologies in rural Tanzania: Implications for program implementation, health and socio economic improvements. *Technol. Soc.* **2016**, *46*, 70–79. [CrossRef]
46. Scott, P.; Cotton, A.; Khan, M.S. Tenure security and household investment decisions for urban sanitation: The case of Dakar, Senegal. *Habitat Int.* **2013**, *40*, 58–64. [CrossRef]
47. Panfil, C.; Mirel, I.; Szigyarto, I.; Isacu, M. Technical, economical, social and ecological characteristics of vacuum sewage system. *Environ. Eng. Manag. J.* **2013**, *12*, 1017–1022. Available online: https://www.cabdirect.org/globalhealth/abstract/20133380245 (accessed on 28 April 2022). [CrossRef]
48. Kwangware, J.; Mayo, A.; Hoko, Z. Sustainability of donor-founded rural water supply and sanitation projects in Mbire district, Zimbabwe. *Phys. Chem. Earth* **2014**, *76–78*, 134–139. [CrossRef]
49. Frone, S.; Frone, D.F. Emerging markets Queries in Finance and Business. Economic risk to a regional water supply and sanitation project in Romania. *Procedia Econ.* **2015**, *32*, 550–557. [CrossRef]
50. Elawwad, A.; Ragab, M.; Abdel-Halim, H. An economical, environmental, and social comparison between vacuum and gravity sewers in decentralized sanitation systems, with Egypt as a case study. *J. Water Sanit. Hyg. Dev.* **2015**, *5*, 614–619. [CrossRef]
51. Genius, M.; Manioudaki, M.; Mokas, E.; Pantagakis, E.; Tampakakis, D.; Tsagarakis, K.P. Estimation of willingness to pay for wastewater treatment. *Water Supply* **2005**, *5*, 105–113. [CrossRef]
52. William, F.; Mozumder, V.P.; Hernández-Arce, J.; Berrens, R.P. Willingness to pay for safe drinking water: Evidence from Parral, Mexico. *J. Environ. Manag.* **2009**, *90*, 3391–3400. [CrossRef]
53. Vouk, D.; Malus, D.; Halkijevic, I. Neural networks in economic analyses of wastewater systems. *Expert Syst. Appl.* **2011**, *38*, 10031–10035. [CrossRef]
54. Karczmarczyk, A.; Bus, A.; Baryła, A. Assessment of the Efficiency, Environmental and Economic Effects of Compact Type On-Site Wastewater Treatment Plants—Results from Random Testing. *Sustainability* **2021**, *13*, 982. [CrossRef]
55. Domínguez, I.; Oviedo-Ocaña, E.R.; Hurtado, K.; Barón, A.; Hall, R.P. Assessing Sustainability in Rural Water Supply Systems in Developing Countries Using a Novel Tool Based on Multi-Criteria Analysis. *Sustainability* **2019**, *11*, 5363. [CrossRef]
56. Metcalfe, P.J.; Sen, A. Sensitivity to scope of water and wastewater service valuations: A meta-analysis of findings from water price reviews in Great Britain. *Rev. Environ. Econ. Policy* **2021**, *11*, 21–38. [CrossRef]
57. Duadey, L. The cost of urban sanitation solutions: A literature review. *J. Water Sanit. Hyg. Dev.* **2018**, *8*, 176–195. [CrossRef]
58. Dz.U. 2018 poz. 472 Rozporządzenie Ministra Gospodarki Morskiej i Żeglugi Śródlądowej z Dnia 27 Lutego 2018 r. w sprawie Określania Taryf, Wzoru Wniosku o Zatwierdzenie Taryfy Oraz Warunków Rozliczeń Za Zbiorowe Zaopatrzenie w Wodę i Zbiorowe Odprowadzanie Ścieków. (In Polish). Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20180000472 (accessed on 28 April 2022).
59. Terryn, J.C.C.; Lazar, I.; Nedeff, V.; Lazar, G. Conventional vs. vacuum sewerage system in rural areas—An economic and environmental approach. *Environ. Eng. Manag. J.* **2014**, *13*, 1847–1859.
60. Le, T.T.P.; Aramaki, T. Factors affecting Households' Willingness to Pay for improved wastewater services in Ho Chi Minh City, Vietnam. *J. Water Environ. Technol.* **2019**, *17*, 163–173. [CrossRef]
61. Willis, K.; Sheldon, R. Research on customers' willingness-to-pay for service changes in UK water company price reviews 1994–2019. *J. Environ. Econ. Policy* **2021**, *11*, 4–20. [CrossRef]
62. Tudela-Mamani, J.W. Willingness to pay for improvements in wastewater treatment: Application of the contingent valuation method in Puno, Peru. *Rev. Chapingo Ser. Cienc. For. Ambiente* **2017**, *23*, 341–352. [CrossRef]

63. Dz.U.2017 poz. 2180. Ustawa z Dnia 27 Października 2017 r. o Zmianie Ustawy o Zbiorowym Zaopatrzeniu w Wodę i Zbiorowym Odprowadzaniu Ścieków Oraz Niektórych Innych Ustaw. (In Polish). Available online: https://isap.sejm.gov.pl/isap.nsf/DocDetails.xsp?id=WDU20170002180 (accessed on 28 April 2022).
64. National Water Holding Polish Waters. Available online: https://odrapcu.pl/en/the-state-water-holding-polish-waters/ (accessed on 28 April 2022).
65. Lista artykułów. Available online: https://wodypolskie.bip.gov.pl/rzgw-w-lublinie-taryfy/ (accessed on 30 April 2022).
66. Sartori, D. Przewodnik Po Analizie Kosztów i Korzyści Projektów Inwestycyjnych. Narzędzie Analizy Ekonomicznej Polityki Spójności 2014–2020. 2014. Available online: https://www.funduszeeuropejskie.gov.pl/media/5594/Przewodnik_AKK_14_20.pdf (accessed on 28 April 2022).
67. Biuletyn Informacji Publicznej Gminy Siemiankowica. (In Polish). Available online: https://siemkowice.biuletyn.net/?bip=2&cid=368&id=2017 (accessed on 28 April 2022).
68. Xu, M.; Zhu, S.; Zhang, Y.; Wang, H.; Fan, B. Spatial-temporal economic analysis of modern sustainable sanitation in rural China: Resource-oriented system. *J. Clean. Prod.* **2019**, *233*, 340–347. [CrossRef]
69. Widomski, M.; Ładziak, E.; Łagód, G. Economic aspects of sustainable sanitation in rural settlements. *Archit. Civ. Eng. Environ.* **2017**, *3*, 153–162. [CrossRef]
70. *PN-EN 752:2008*; Zewnętrzne Systemy Kanalizacyjne. Polish Committee for Standardization: Warsaw, Poland, 2008. (In Polish)
71. Kalenik, M. *Zaopatrzenie w Wodę i Odprowadzanie Ścieków*; Wydawnictwo SGGW: Warszawa, Poland, 2015. (In Polish)
72. Płuciennik, S.; Wilbik, J. *Warunki Techniczne Wykonania i Odbioru Sieci Kanalizacyjnych*; COBRTI Instal: Warszawa, Poland, 2003. (In Polish)
73. Commission Delegated Regulation (EU) No 480/2014 of 3 March 2014 Supplementing Regulation (EU) No 1303/2013 of the European Parliament and of the Council Laying down Common Provisions on the European Regional Development Fund, the European Social Fund, the Cohesion Fund, the European Agricultural Fund for Rural Development and the European Maritime and Fisheries Fund and Laying down General Provisions on the European Regional Development Fund, the European Social Fund, the Cohesion Fund and the European Maritime and Fisheries Fund. (In Polish). Available online: https://www.funduszeeuropejskie.gov.pl/media/5190/NOWE_RD_480_2014.pdf (accessed on 28 April 2022).
74. Palme, U.; Lundin, M.; Tillman, A.M.; Molander, S. Sustainable development indicators for wastewater systems—Researchers and indicator users in a co-operative case study. *Resour. Conserv. Recycl.* **2005**, *43*, 293–311. [CrossRef]
75. Palme, U.; Tillman, A.M. Sustainable development indicators: How are they used in Swedish water utilities. *J. Clean. Prod.* **2008**, *16*, 1346–1357. [CrossRef]
76. Bouabid, A.; Louis, G. Decision support system for selection of appropriate water supply and sanitation technologies in developing countries. *J. Water Sanit. Hyg. Dev.* **2015**, *11*, 208–221. [CrossRef]
77. Studium Wykonalności POIiŚ Oś Priorytetowa 2.3. "Budowa Kanalizacji Sanitarnej Wraz z Przyłączami w m. Radków" Etap V, VI, VII. 2016. Available online: https://www.google.com/url?sa=t&rct=j&q=&esrc=s&source=web&cd=&ved=2ahUKEwi_ovG3guv0AhVJxIsKHVX8CXkQFnoECAIQAQ&url=https%3A%2F%2Fwww.prawomiejscowe.pl%2Fapi%2Ffile%2FGetZipxAttachment%2F8%2F35207%2Fpreview&usg=AOvVaw054GP5a7tDUqAfCiBP3qx5 (accessed on 1 April 2022).
78. Pochwat, K.; Kida, M.; Ziembowicz, S.; Koszelnik, P. Odours in Sewerage—A Description of Emissions and of Technical Abatement Measures. *Environments* **2019**, *6*, 89. [CrossRef]
79. Shammay, A.; Sivret, E.C.; Le-Minh, N.; Fernandez, R.L.; Evanson, I.; Stuetz, R.M. Review of odour abatement in sewer networks. *J. Environ. Chem. Eng.* **2016**, *4*, 3866–3881. [CrossRef]
80. Kazora, A.S.; Mourad, K.A. Assessing the Sustainability of Decentralized Wastewater Treatment Systems in Rwanda. *Sustainability* **2018**, *10*, 4617. [CrossRef]
81. Brands, E. Prospects and challenges for sustainable sanitation in developed nations: A critical review. *Environ. Rev.* **2013**, *22*, 346–363. [CrossRef]
82. Weststrate, J.; Dijkstra, G.; Eshuis, J.; Gianoli, A.; Rusca, M. The Sustainable Development Goal on Water and Sanitation: Learning from the Millennium Development Goals. *Soc. Indic. Res.* **2019**, *143*, 795–810. [CrossRef]
83. Suchorab, P.; Iwanek, M.; Głowacka, A. Ocena efektywności ekonomicznej wybranych systemów kanalizacji sanitarnej. *Czas. Inżynierii Lądowej Sr. Archit.* **2015**, *32*, 447–456. (In Polish). Available online: https://www.researchgate.net/publication/298731647_Ocena_efektywnosci_ekonomicznej_wybranych_systemow_kanalizacji_sanitarnej (accessed on 1 April 2022). [CrossRef]
84. Miłaszewski, R. *Ekonomika Ochrony Wód Powierzchniowych (Economics of Surface Water Protection)*; Wydawnictwo Ekonomia i Środowisko: Białystok, Poland, 2003. (In Polish)
85. Martínez-Córdoba, P.J.; Raimo, N.; Vitolla, F.; Benito, B. Achieving Sustainable Development Goals. Efficiency in the Spanish Clean Water and Sanitation Sector. *Sustainability* **2020**, *12*, 3015. [CrossRef]
86. Flores, A.; Buckley, C.; Fenner, R. Selecting sanitation systems for sustainability in developing countries. *Water Sci. Technol.* **2009**, *60*, 2973–2982. [CrossRef]
87. Schertenleib, R. From conventional to advanced environmental sanitation. *Water Sci. Technol.* **2005**, *51*, 7–14. [CrossRef]
88. Boguniewicz-Zabłocka, J.; Capodagli, A.G. Sustainable Wastewater Treatment Solutions for Rural Communities: Public (Centralized) or Individual (On-Site)—Case Study. *Econ. Environ. Stud.* **2017**, *4*, 1103–1119. Available online: https://www.ceeol.com/search/article-detail?id=608286 (accessed on 28 April 2022). [CrossRef]