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Comparative analysis of selected wastewater treatment plants

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ABSTRACT

The article presents the classification of wastewater treatment plants and indicates the types of processes occurring during wastewater treatment. The purpose of the article is to get acquainted with the functioning as well as technical and economic differences of biological and mechanical-biological wastewater treatment plant. The author also made a comparative analysis containing a list of wastewater treatment efficiency in the presented treatment plants, as well as compared economic aspects necessary for the operation of these treatment plants.

Keywords: wastewater, biological wastewater treatment plant, mechanical-biological wastewater treatment plant, wastewater management

1. INTRODUCTION

Almost all natural waters, before their use for drinking and for economic or industrial needs, must be properly prepared, which is achieved in the processes of their purification. The current level of technical knowledge allows the treatment of the most polluted waters. However, economic considerations favor the recognition of the best-quality waters because the costs of purification increase disproportionately with the degree of water pollution.. The type of unit processes used followed by the purification system depends on the type of substances that must be removed from the water. Each technological system of water

treatment is an ordered collection of physical operations and chemical, physico-chemical, biological, biochemical strictly integrated with each other. The immediate purpose of the purification is to change the composition and properties of wastewater by discharging them to the receiver in such a way that it does not affect its natural life and does not constitute an obstacle to the further use of water and does not threaten human and animal health.

2. CHARACTERISTICS AND CLASSIFICATION OF WASTEWATER

In households or in industrial plants, the majority of water consumed is contaminated. The cause of these impurities are solid substances (eg sand) and liquids (eg milk). The contaminations can be divided into soluble and insoluble. Another classification is the split of sewage according to the chemical composition: organic (eg protein, fats, carbohydrates), and inorganic also called mineral (eg sand, salts, metals). Wastewater is a mixture of mineral and organic substances [1]. Wastewater are classified in Table 1 because of its source.

Table 1. Types and division of wastewater

Name	Classification
Sewage	wastewater from buildings intended for human stay, from housing estates and service areas, arising as a result of human metabolism and functioning of households
Municipal sewage	domestic wastewater or a mixture of domestic sewage with industrial wastewater or waste water
Industrial wastewater	wastewater discharged from areas where commercial, industrial or landfill operations are carried out, not being domestic sewage or rainwater

[Source: own elaboration]

Wastewater is already used water, especially for living or economic purposes. Sewage is also rainwater or snowmelt water, included in open or closed sewage systems, originating from contaminated surfaces in particular from cities, industrial, commercial, service and storage areas, transport bases, roads and parking lots. A special type of sewage is water from landfills and from mining plants and water discharged from animal housing or fish farms. The most general and at the same time accurate definition of wastewater is: water which had already been used and that is not suitable for the same use again. [2]

The composition and amount of wastewater depends on the industrialization of the city, the type and technical condition of the sewage system and the amount of water used.

To determine the properties of wastewater, firstly their appearance and odor assessed and their physical and chemical properties are examined. The most important features and substances that inform us about the properties of wastewater are: color, odor, turbidity, temperature, reaction, easily drooping suspensions and general, organic and inorganic

substances, soluble and insoluble substances, poisonous substances, oils, fats, flammable substances and explosive, infectious substances, detergents, combability (durability), electrolytic conductivity (salt content) [3].

Wastewater composition is determined by means of pollution indicators [4]:

- BOD₅
- COD
- Total suspension;
- Total nitrogen;
- Total phosphorus

The interpretation and measurement methods for the listed pollution indicators are presented below:

- BOD₅ - Five-day biochemical oxygen demand

When determining the BOD₅ value, the oxygen demand, consumed by microorganisms within five days and at 20 °C to decompose organic substances is measured.

- COD - Chemical oxygen demand

In determining the COD value, the chemical consumption of oxygen contained in a given oxidizing compound is measured, necessary for the oxidation of organic and inorganic compounds contained in wastewater.

- total suspension

The indicator of dissolved substances determines the mass of dissolved pollutants, both mineral and organic, contained in wastewater, which are determined by evaporating the filtered wastewater sample and drying it to a constant weight. The content of mineral compounds dissolved in sewage is determined by the mineral (non-volatile) indicator of dissolved substances, and it is determined by calcination at 600 °C of dissolved substances. The difference between the value of indicators of dissolved substances and minerals of dissolved substances determines approximately the mass of dissolved organic compounds. Knowledge of the above indicators makes it possible to calculate the content in general suspension wastewater.

- total Nitrogen

Total nitrogen is the sum of organic, ammonium, nitrite and nitrate nitrogen. Nitrogen compounds have a diverse effect on water reservoirs, namely they are highly poisonous for fish, have eutrophic effects as well as compounds that strongly absorb oxygen. The largest sources of nitrogen compounds are various kinds of wastewater and runoff from intensively used agricultural areas.

- total phosphorus

Total phosphorus is the sum of three forms of phosphorus: orthophosphates, polyphosphates and organically bound phosphorus. Phosphorus, like nitrogen, belongs to the group of biogenic elements necessary for the development of flora and fauna in water reservoirs. Excessive amounts of phosphorus supplied to the receiver cause an intensified increase in algae biomass. Dying cells are a source of organic pollution, the decomposition of which requires additional amounts of oxygen. The decreasing oxygen concentration in the water of receivers is the cause of death of the organisms present in them, and hence of secondary pollution caused by the additional charge of organic compounds and biogenic elements.

Table 2 presents the maximum permissible values of pollution indicators or minimum percentages of reduction of pollutants for treated municipal sewage introduced into waters and land in Poland [5, 19].

Table 2. The highest permissible values of pollution indicators for treated domestic and municipal sewage.

No.	The name of the indicator	Unit	Maximum permissible values of indicators and / or reduction requirements for pollutants at PE:				
			from 2000	from 2000 to 9999	from 10000 to 14999	from 15000 to 99999	More than 100 000
1	Five-day biochemical oxygen demand (BOD ₅) determined with the addition of an inhibitor of nitrification	mg O ₂ /l min. % reduction	40-	25 or 70-90	25 or 70-90	15 or 90	15 or 90
2	Chemical oxygen demand (COD) determined by the dichromate method	mg O ₂ /l min. % reduction	150-	125 or 75	125 or 75	125 or 75	125 or 75
3	Total suspension	mg/l min. % reduction	50	35 or 90	35 or 90	35 or 90	35 or 90

4	Total nitrogen	mg N/l min. % reduction	Normative indices only in cases of sewage discharges to lakes	15 or 80	10 or 85
5	Total phosphorus	mg P/l min. % reduction		21 or 85	1 or 90

[Source: own elaboration]

3. CLASSIFICATION AND OBJECTIVES OF WASTEWATER TREATMENT PLANTS

The general purpose of a wastewater treatment plant is to protect the natural environment from pollution arising as a result of human life and economic activity.

There are many dangerous factors in domestic and industrial sewage, among which one can be distinguished:

- parasites and pathogenic microorganisms,
- toxic substances,
- substances that disrupt the natural balance of the receivers by increasing their saprobia or eutrophication. [6]

The concept of wastewater treatment plant should be understood as a set of technological buildings serving directly to wastewater treatment and disposal of sewage sludge, as well as facilities located on the common area necessary for energy supply and to create appropriate conditions for the operation, management and control of technological processes. [7] Figure 1 presents the types of wastewater plants due to the applied methods of wastewater treatment and related processes.

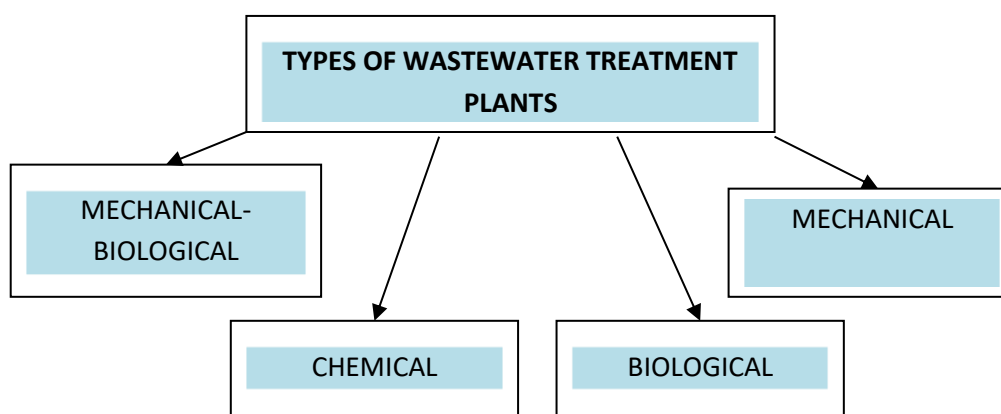


Figure 1. Types of wastewater treatment plants due to the type of wastewater treatment methods

[Source: own elaboration]

Depending on the type of treatment plant (eg mechanical, chemical), and on the type of technologies used (eg biological beds, activated sludge chambers), different treatment plants are used. Technological solutions of wastewater treatment plants and their diagrams are related to the area from which wastewater is discharged. We distinguish two types of wastewater treatment plants:

- collective - intended for sewage discharged from settlement units of various sizes,
- operating household - intended for sewage discharged from individual houses, or from their small groupings.

Depending on the type of wastewater treated, we divide the treatment plants into:

- domestic-communal wastewater treatment plants,
- industrial wastewater treatment plants [8].

In the presented article, the attention was paid to biological and mechanical-biological wastewater treatment plants.

Biological wastewater treatment plant

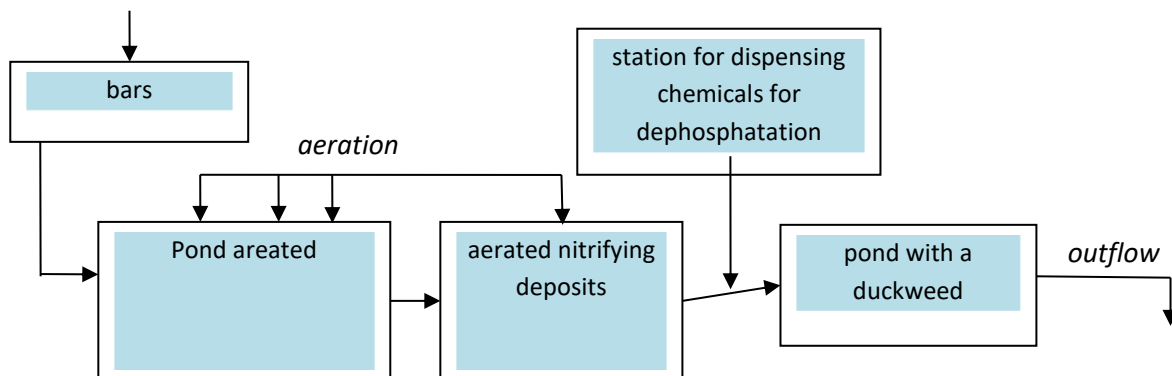


Figure 2. A diagram of a biological treatment plant.

[Source: own elaboration]

Wastewater treatment using biological wastewater treatment plants can be carried out in natural, semi-natural and artificial conditions.

Biological treatment of wastewater in natural conditions consists in discharging them to rivers, lakes, the sea, leaving for self-cleaning through water, it should be remembered that the possibilities of such treatment are very limited and involve high risk. Currently, such activities are undertaken only with sewage biologically purified in artificial conditions [9]. Biological treatment of wastewater in semi-natural conditions consists in the intentional adaptation by means of technical means of the natural water environment. At the same time, there is an economic use of biochemical transformation products taking place in such an organized natural environment. In this type of wastewater treatment, we can use devices for the use of wastewater in agriculture and forestry, eg sewage ponds.

Biological treatment of wastewater under artificial conditions consists in multiple intensification of biochemical processes of decomposition of organic substances occurring in natural or semi-natural conditions. This is due to the use of appropriate technical devices and creating in them optimal conditions for an organic set of living organisms being a certain section of the natural environment [10]. Figure 2 presents a diagram of a biological treatment plant.

Mechanical- biological wastewater treatment plant

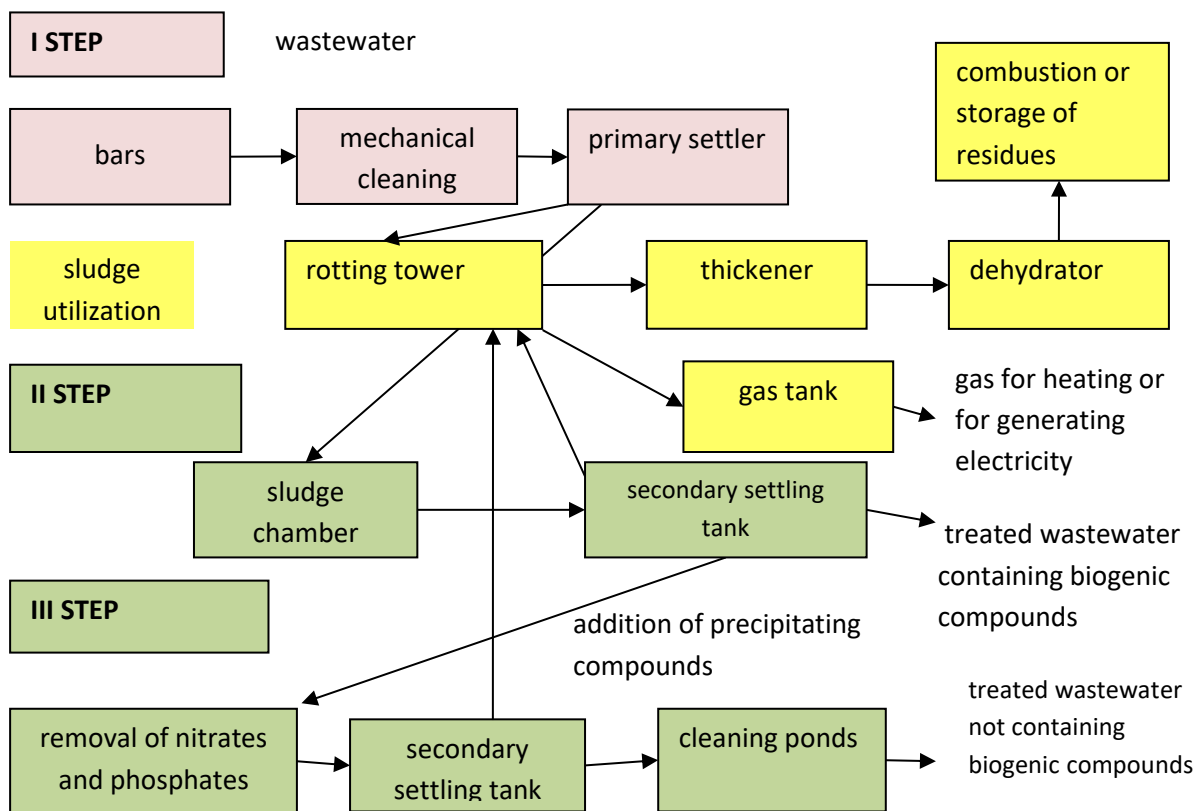


Figure 3. Wastewater treatment diagram.
[Source: own elaboration]

The first stage of treatment is called mechanical cleaning, during which insoluble debris is removed: larger floating bodies - using grids and sieves, heavy granular suspensions - in sand traps, fats and oils - in degreasers, fine suspensions - in settling tanks. It is this degree that is responsible for the first contact with sewage and its preliminary cleaning, it is called mechanical cleaning. The second stage of urban wastewater treatment as well as industrial wastewater is biological treatment. During the process, there is a biochemical decomposition of organic compounds. The whole process takes place under the influence of microorganisms in aeration chambers with activated sludge. The activated sludge is a set of microorganisms composed of bacteria, microscopic fungi and protozoa. The sludge microflora contributes to the decomposition of organic compounds that occur in wastewater. The third stage of

wastewater treatment is the removal of inorganic (mineral) substances, which mainly include phosphates and nitrates, which were produced during the second stage of wastewater treatment. [11] Figure 3 presents a diagram showing the stages of wastewater treatment in a mechanical-biological treatment plant.

Natural wastewater treatment processes occurring in surface waters are used in wastewater treatment plants. By means of the natural processes used, the same and even better effects of wastewater treatment are achieved within a few hours than those that would have been going on for many days in a river or other receiver. This is especially true for the biological part of the treatment plant. Useful bacteria found in raw sewage are artificially produced in large quantities on sprinkled beds or in activated sludge chambers. Through the appropriate use of technical procedures, bacteria provide excellent living conditions by supplying oxygen for breathing and food in the form of an inflow of pollutants. Of course, wastewater must be pre-treated mechanically to prevent disruption to the treatment plant and economic operation. The collective treatment plants use various types of treatment. In the case of removing solid contaminants, easily falling suspensions and floating substances on the water surface, such a process is called mechanical cleaning. Mechanical wastewater treatment requires the use of bars, sand traps and pre-settling tanks. The sediments separated in settling tanks are often subjected to a biochemical fermentation process, which stabilizes the sediments, depriving them of the ability to crush and secrete unpleasant odors. In a mechanical treatment process, no more than 20-30% of impurities are removed from sewage. The remainder of the impurities in the form of dissolved organic compounds and non-absorbable suspensions are removed by biological purification, which decomposes 90-98% of organic pollutants [16, 18].

Also nitrogen and phosphorus being fertilizers and nutrients are a burden for surface waters, so their load must be reduced. Lowering the content of nitrogen compounds is achieved using biological processes while phosphorus compounds using chemical processes.

Summing up in the above reference, basically in the sphere of wastewater treatment plants, we distinguish:

- mechanical processes,
- biological processes,
- chemical processes [12].

Mechanical processes

The division of mechanical processes is presented in Figure 4.

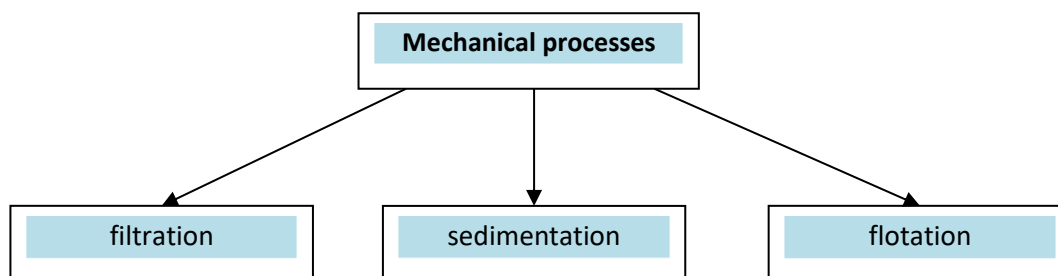


Figure 4. The division of mechanical processes.

[Source: own elaboration]

As a result of the process of filtration carried out on lattices and sieves, sewage is deprived of larger solid contaminants floating or dragged along the bottom of the channel to the sewage treatment plant. As a result of the gravitational sedimentation process, mineral submissions are mainly removed, settling in sand traps, while the remaining organic matter suspensions are eliminated in pre-settling tanks. Oils and fats often present in wastewater are removed simultaneously with the sedimentation process in sand traps or preliminary settling tanks or in so-called degreasers as a result of the flotation process consisting in separating the fraction lighter than water [13].

Biological processes

Figure 5 shows examples of biological wastewater treatment technologies.

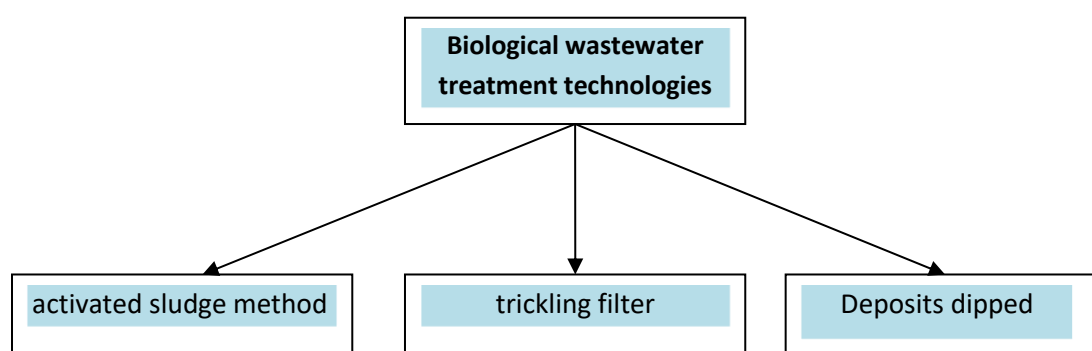


Figure 5. Examples of biological wastewater treatment technologies.

[Source: own elaboration]

During biological wastewater treatment, organic pollutants become food for certain types of mucus-producing bacteria. In optimal conditions, the process of their multiplication is very fast. During these processes, organic substances are oxidised, resulting in the formation of water-soluble mineral salts and carbonic acid. Some organic substances are used to build cells. During combustion, the energy necessary for life is created. The oxygen required for this is taken by breathing. The efficient functioning of biological wastewater treatment depends on sufficient oxygen supply and good contact of microorganisms with wastewater. Biological purification processes consist in the transformation (by means of microorganisms) of non-falling and dissolved pollutants into harmless, water-soluble substances. Among biological processes, we can distinguish coal distribution and removal of nitrogen compounds [14].

Chemical processes

The division of chemical processes due to the technology used in wastewater treatment is shown in Figure 6.

Naturalization - this is the reaction of neutralizing the acid with the base. The sewage naturalization is necessary because the pH value of 7,5 is favorable for biological wastewater treatment processes.

Precipitation - the process consists in converting soluble wastewater components into an insoluble form, with the help of chemical reactions with precipitating compounds (coagulants). In this process, heavy metal salts and phosphorus compounds are removed from wastewater.

Flocculation - involves the production of flocs capable of sedimentation from insoluble suspensions. Flocculants are called chemical compounds that form flocs in water (eg iron salts).

Detoxification (neutralization of toxic substances) - it is the disposal of poisonous substances contained in wastewater, it consists in eliminating the poisonous action of substances or compounds. The most important poisons contained in the sewage are cyanides, chromates, nitrites, sulphides [15].

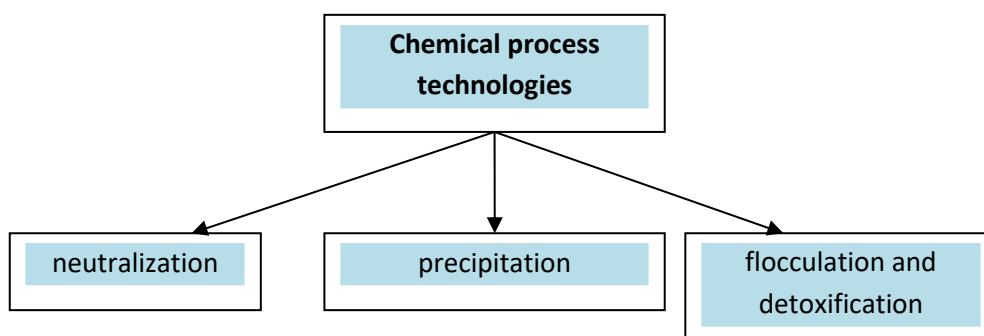


Figure 6. Division of chemical processes due to technology
[Source: own elaboration]

4. ANALYSIS OF SELECTED TREATMENT PLANTS

This point presents a comparative analysis, which includes a summary of efficiency of wastewater treatment in two selected wastewater treatment plants in Poland: biological (Y) and mechanical-biological (X) wastewater treatment plant. The examined treatment plants are located in one commune, in two neighboring villages in the Silesian Voivodeship. The author also compared economic aspects necessary for the operation and operation of the above mentioned sewage treatment plants.

The above table shows that domestic and economic sewage supplied to the tested treatment plants may differ in terms of the value of basic physico-chemical properties. The reason for these differences may be various types of compounds washed away from agricultural land, after artificial fertilizers and plant protection products. Waste discharges from nearby production plants with different profiles may also contribute to these differences. The current state of the mechanical and biological wastewater treatment plant allows to obtain very good technical efficiency of the functioning of the equipment, thanks to this the parameters of treated wastewater are within the norm as can be seen in Figure 7.

Table 3. Selected properties of raw and treated sewage and the degree of purification in the analyzed objects

Parameter		Condition of raw and treated wastewater					
		Wastewater plant X			Wastewater plant Y		
		Raw	Treated	Permissible content	Raw	Treated	Permissible content
Submission	mg/dm ³	360	7,2	25-35	534	50	25-35
BOD ₅	mgO ₂ /dm ³	163	12	20-25	209	23	20-25
COD	mgO ₂ /dm ³	290	54	125	659	94	125
Total nitrogen	mgN/dm ³	Lack of data			45	15	30
Total phosphorus	mgP/dm ³				11	1	5

[Source: own elaboration]

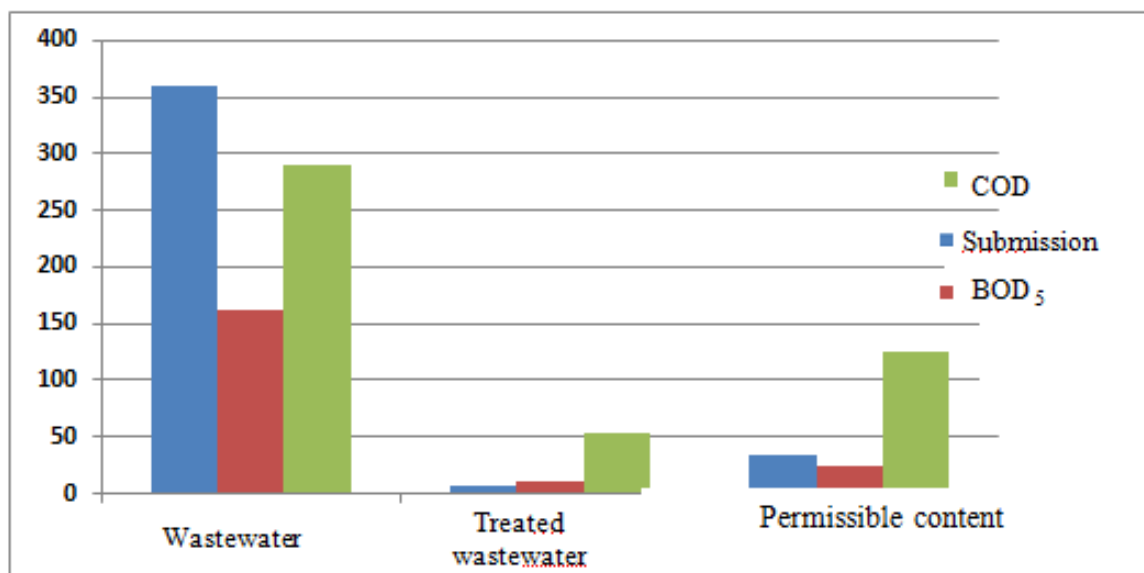


Figure 7. Selected properties of raw and treated sewage and the degree of purification expressed in [mg / dm³] in a mechanical and biological treatment plant.

[Source: own elaboration]

The above table shows that domestic and economic sewage supplied to the tested treatment plants may differ in terms of the value of basic physico-chemical properties. The reason for these differences may be various types of compounds washed away from agricultural land, after artificial fertilizers and plant protection products. Waste discharges from nearby production plants with different profiles may also contribute to these differences. The current state of the mechanical and biological wastewater treatment plant allows to obtain very good technical efficiency of the functioning of the equipment, thanks to this the parameters of treated wastewater are within the norm as can be seen in Figure 7.

In contrast, in the biological treatment plant, the slurry values exceed the permissible standard as shown in Figure 8. The reason for this condition could have been atmospheric precipitation.

The remaining indicators are located in norme.

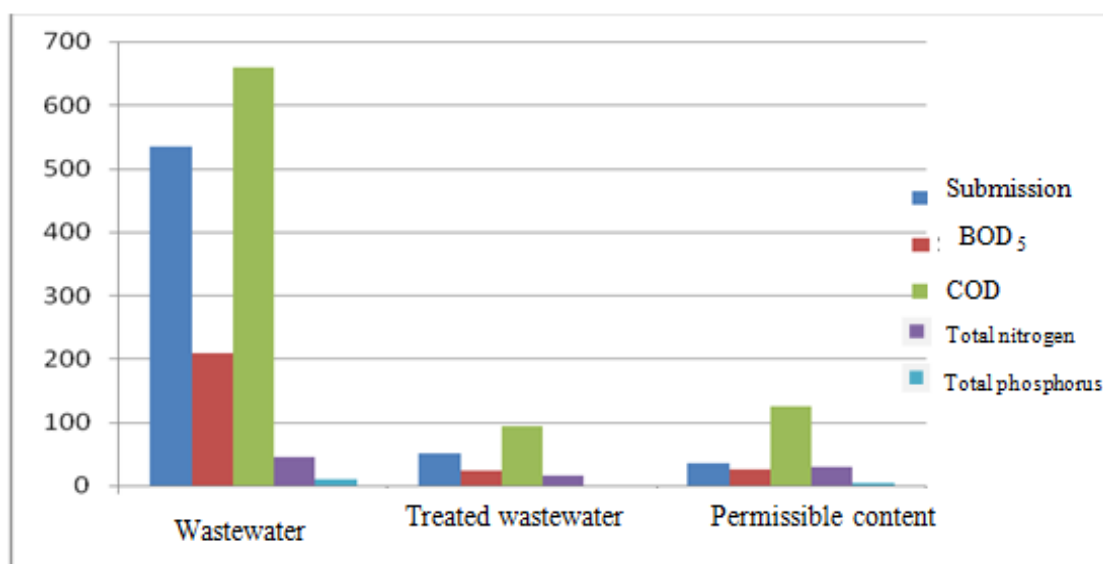


Figure 8. Selected properties of raw and treated wastewater and the degree of purification expressed in [mg / dm³] in a biological treatment plant.

[Source: own elaboration]

The economic aspect:

The cost of building a mechanical and biological treatment plant (X) is: PLN 10,220,000.

The cost of constructing a biological treatment plant is (Y): PLN 2,100,000.

As shown in Figure 9, the construction cost of the mechanical - biological treatment plant was five times higher than the cost of building a biological treatment plant.

Electricity consumption for 1 m³ of treated wastewater in biological treatment plant is 700,000 kWh / year.

Electricity consumption for 1 m³ of treated wastewater in a mechanical-biological treatment plant is 1,250,000 kWh / year.

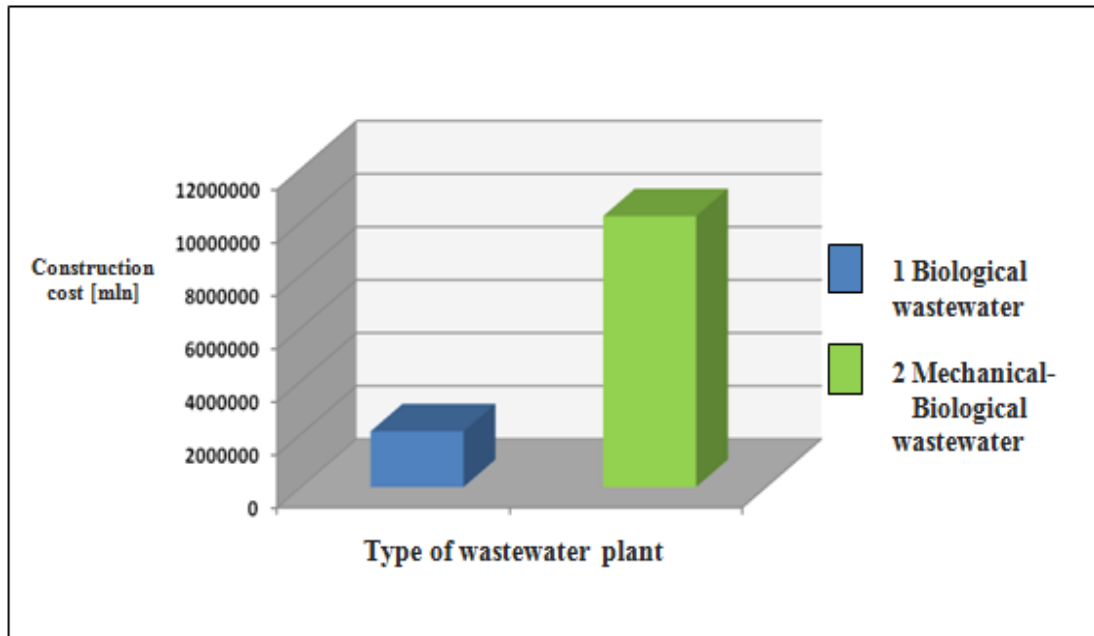


Figure 9. The cost of building a sewage treatment plant
[Source: own elaboration]

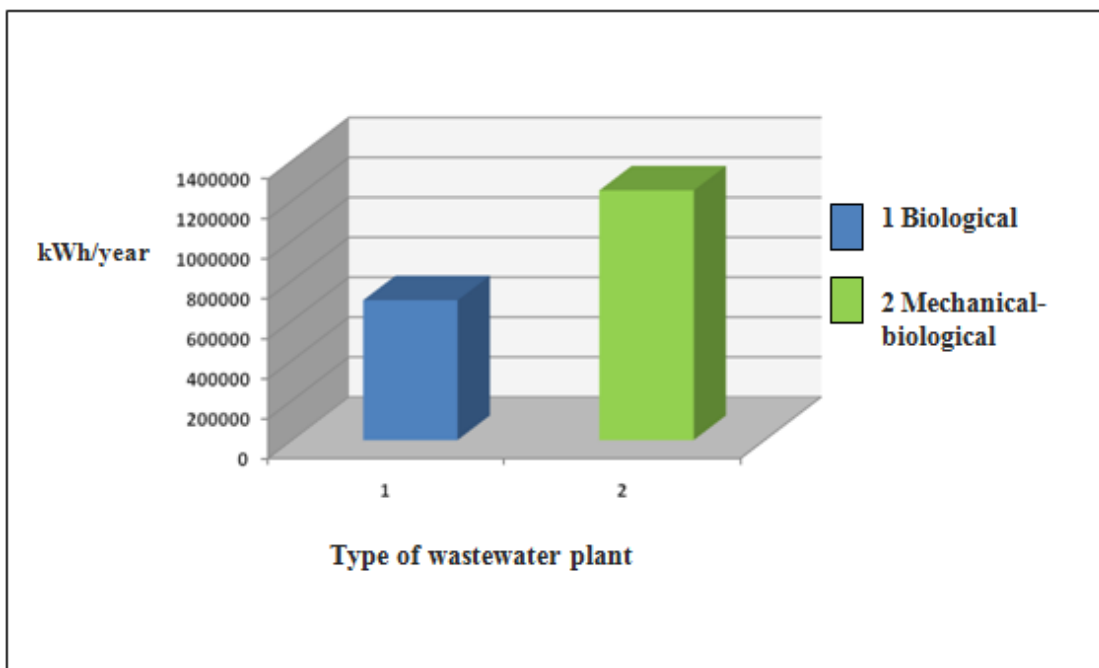


Figure 10. Electricity consumption for 1 m³ of treated wastewater
[Source: own elaboration]

In Figure 10, we can notice much lower electricity consumption for a biological treatment plant, which is 700,000 kWh / year, while for a biological and biological treatment plant it is 1,250,000 kWh / year. The mechanical treatment plant consumes more energy due to the installation of numerous devices that draw electricity. In contrast, the biological treatment plant is more efficient because it processes once again the same amount of wastewater as the biological treatment plant.

The number of inhabitants in the village of X amounts to 2044.

The number of inhabitants in the village of Y amounts to 4002.

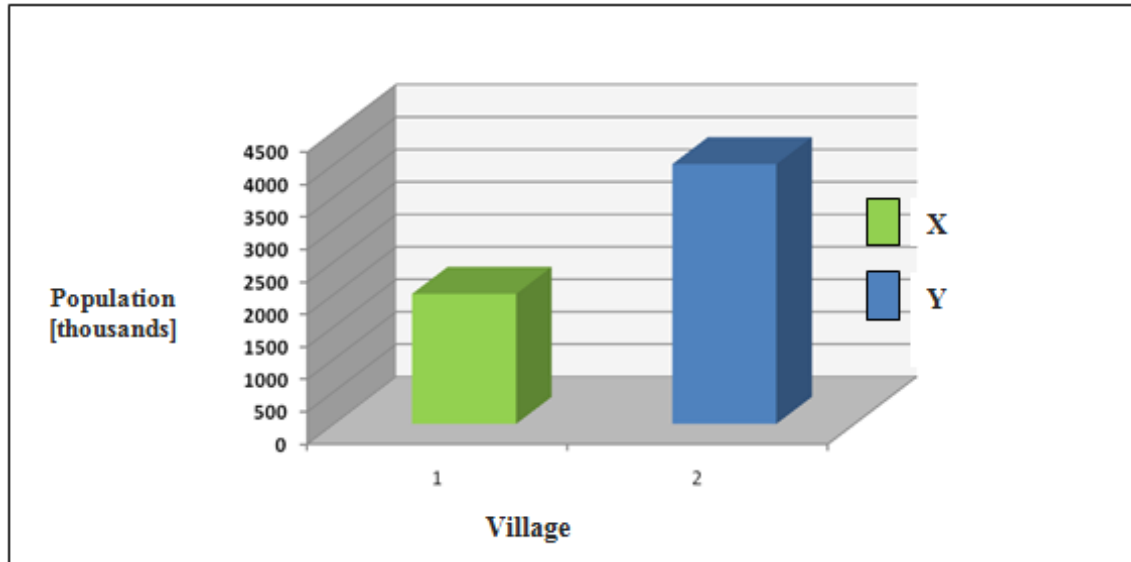


Figure 11. Population in the analyzed villages.

[Source: own elaboration]

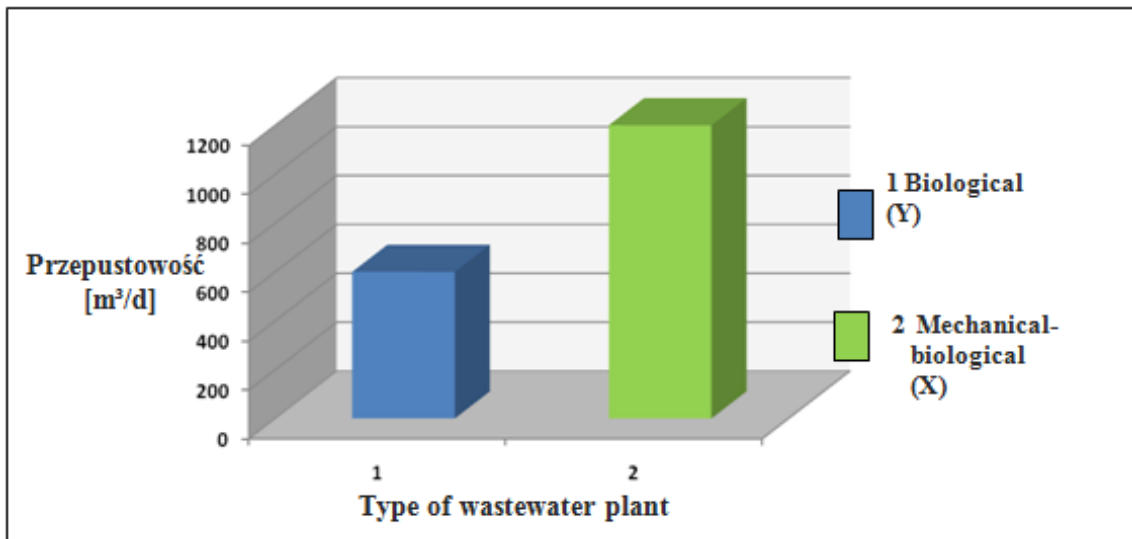


Figure 12. Comparison of the mechanical-biological and biological efficiency of the treatment wastewater plant.

[Source: own elaboration]

Figure 11 shows that the number of inhabitants in village X is smaller than the number of inhabitants in village Y, while the efficiency of the treatment plant in village Y (Figure 12) is much smaller, therefore it must be modernized in the near future.

5. CONCLUSIONS

The aim of the article was to conduct a comparative analysis of the tested treatment plants, which allowed to conclude that a better solution for the studied municipality is a mechanical - biological treatment plant. The treatment plant is very efficient and has the possibility of expanding to reach the target throughput of 1 800 m³ / d. After such changes, such a reactor can purify wastewater from small or medium cities. In connection with the conducted research, the mechanical- biological treatment plant can be recommended as an investment that brings better effects for the commune.

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