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THE CHOICE OF LOCATION FOR A COMMUNITY WATER TREATMENT PLANT USING THE AHP METHOD

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ABSTRACT: The aim of the research was to identify the location of the local sewage treatment plant with use of hierarchical multi-criteria analytical analysis: AHP (Analytical Hierarchy Process) taking into account the technical, economic, and social criteria. The analysis was carried out for the rural commune of Szumowo (Zambrów district) which since 2016 forms an agglomeration. According to the Functional and Utility Programme a sewage treatment plant with a capacity of 350 m^3/d was proposed, taking into account 4 location variants with an area of approx. 1.3 ha.

KEY WORDS: sewage treatment plants, AHP, multicriteria decision, rural areas

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Introduction

Regulation of wastewater management, in addition to providing people access to clean water, is one of the most important activities. Developing water and wastewater management can improve health and lead to economic expansion.

In rural areas, similar to the urban areas in range of produced sewage amount, we can observe large disproportion between water and wastewater systems length. Sustainable environmental development should lead to reduce this disproportion. The dispersed development and low settlement concentration in rural areas are the key issue when designing wastewater management.

Selection of location is a commonly experienced strategic problem, not only in wastewater management. Selecting sites for small wastewater-treatment plants depend on many technical, environmental, social and economic aspects. It may be achieved by using the multi-criteria decision making, evaluating different alternatives and variants to compare different sides of analysed problem (Janssen, 2001).

In rural areas a key issue is to decide installation of central wastewater system or local small household treatment plants. Rural areas produce almost half of the sewage in Poland, but predominant septic tanks are often old and in poor technical condition (LPO-4010-003/2011). Planning of wastewater systems should be based on the principles of sustainable development, and therefore consider political, economic and social aspects in accordance with environment balance and sustainability of fundamental natural processes (Journal of Laws 2001 no. 62 pos. 627, Consolidation). In the rural areas there are some difficulties we need to manage while preparing the wastewater management plans (ATV A 200, 1997):

- low settlement concentration,
- unfavourable population trends – countryside depopulation,
- settlements with scattered buildings,
- small villages and districts distant from each other,
- low ratios of covered surface (up to 20% of the settlement areas),
- low implementation of sewage and treatment systems,
- high ratio of areas under environmental protection,
- frequent seasonal variation of the wastewater amounts due to tourism.

This paper focuses on small wastewater treatment plant location within rural commune's area. The AHP method and Expert Choice 11 software was used to compare and rank alternative sites in relation to offered weights.

Analytical Hierarchy Process

The multi-criteria decision making methods are techniques supporting the decision maker facing a problem that has several alternatives.

The AHP is based on the experience gained by its developer, T.L. Saaty, while providing research projects in the US Arms Control and Disarmament Agency. It was developed as a reaction to the finding that there is a miserable lack of common, easily understood and easy-to-implement methodology to enable making of complex decisions (Saaty, 1980).

Since then the AHP has gained popularity across multiple domains in every part of the world. The AHP has found use in business, government, social studies, defence, and many others, involving decisions in which choice, prioritization, or forecasting is needed (Bhushan, Rai, 2004).

Making decision according to AHP method includes the following steps (Saaty, 2008):

- Define the problem and determine the kind of knowledge sought.
- Structure the decision hierarchy from the top with the goal of the decision, then the objectives from a broad perspective, through the intermediate levels (criteria on which the subsequent elements depend) to the lowest level (which usually is a set of alternatives).
- Construct a set of pairwise comparison matrices. Each element in an upper level is used to compare the elements in the level immediately below with respect to it.
- Use the priorities obtained from the comparisons to weigh the priorities in the level immediately below. Do this for each element. Then for each element in the level below add its weighed values and obtain its overall or global priority. Continue this process of weighing and adding until the final priorities of the alternatives in the bottom most level are obtained.

Comparisons are made using the importance scale of numbers (table 1).

Verifying the results' reliability is made by calculating the consistency index (CI) and the consistency ratio (CR). In order to eliminate the noncompliance, the CR ratio is calculated according to (Saaty, 2001):

$$CR = \frac{CI}{RI} \cdot 100\%, \tag{1}$$

where RI (Random Consistency Index – Golden and Wang, 1990) is related to the dimension of the matrix. Consistency Index is determined according to:

$$CR = \frac{(\lambda_{max}) - n}{(n-1)}, \qquad (2)$$

where λ_max is maximum eigen value of matrix (eigen values calculations are explained e.g. in: Ostręga, 2004). CI less than 0.1 means, that pairwise comparison and evaluation results are acceptable.

Table 1. Scale of numbers in AHP

Intensity of Importance	Definition	Explanation
1	Equal importance	Two activities contribute equally to the objective
3	Moderate importance	Experience and judgement slightly favour one activity over another
5	Strong importance	Experience and judgement strongly favour one activity over another
7	Very strong or demonstrated importance	An activity is favoured very strongly over another; its dominance demonstrated in practice
9	Extreme importance	The evidence favouring one activity over another is of the highest possible order of affirmation

Source: Saaty, 1996.

Research area and method

Szumowo Commune, of area of 141.15 km², is located in Podlaskie Voivodeship, in the south-west part of the Zambrowski District. Over 70% of land is under agricultural use (Uchwała Nr XXI/103/04). The analysed area is not currently supplied with sewage systems, although until 2019 the commune will build pressure sewer and plug in at least 410 households (http://www.szumowo.pl). On the other hand about 95.6% of commune population have access to the waterworks. Szumowo forms an agglomeration according to the Polish Water Law, with an equivalent of 2527 inhabitants – Szumowo city and Nowe Szumowo, Srebrna villages (Resolution No. XXIX/263/2016).

The study aims to provide an evaluation of four small wastewater treatment plant locations in rural commune, based on seven criteria using the AHP method. For Szumowo Commune the modular wastewater treatment plant with sewage flow of 360 m^3/d, composed of mechanical (bar screens, mesh screens), biological (sewage reactors, primary and final sedimentation) and sludge section (dewatering press) has been proposed (RRG.271.5.2018).

The following criteria were considered:

- Economic:
  - Cr4: parcel cost,
  - Cr5: parcel adaptation cost.
  - Social:
  - Cr6: distance from the residential buildings,
  - Cr7: natural barriers between the residential buildings and WTP (wastewater treatment plant),
- technical:
  - Cr1: distance from the road,
  - Cr2: distance from the sewage receiver,
  - Cr3: network length needed to connect WTP with sewage system,
- economic:
  - Cr4: parcel cost,
  - Cr5: parcel adaptation cost,
- social:
  - Cr6: distance from the residential buildings,
  - Cr7: natural barriers between the residential buildings and WTP.

The analysed commune do not possess any suitable property, which is why all analysed variants require purchase. Parcel adaptation costs were based on the average cost of trees and bushes removal, terrain denivelation, and media connections.

Potential locations of small wastewater treatment plant were selected determining its area for about 1.3 ha (figure 1). The first variant (W1), proposed in the functional and utility programme prepared for the commune (GLOBAL TECHNICS, 2017), is located in IV and V class meadow area, without road infrastructure and other media. This option was selected because of its location in relation to sewage receiver – Szumowo Łętownica Channel as Bug tributary. The second site (W2) also provides discharge to Łętownica Channel for the sewage. In contrast to the situation in W1 this variant is located closest to the road. The third variant (W3) is located near the road leading to Srebrna village, which is a part of agglomeration and will be developed with sewage system. This location, along with W4, involve sewage disposal into Jasionka River (Bug tributary). The last selected variant (W4) is located southwest from Szumowo and includes the highest distance from the sewage receiver – about 450 m.

After agglomeration and sewage system plan studies it was found that variant 4 area is located nearest to the sewerage (130 m) while other variants are located 260 m (W1), 300 m (W3), and 400 m (W2) from the sewerage.

Figure 1.
Small wastewater treatment plant location variants within Szumowo Commune

Source: Google Maps, 2018.

Regarding to the economic criteria, the most advantageous alternative seems to be W3, which together with W4 are the least expensive. Moreover, parcel number 3 requires the lowest adaptation cost.

Likewise the technical and economic criteria, social requirements were analysed. The largest distance from the residential buildings – 400 m – was presented by variants W2 and W3, which have natural barriers in form of forestation stripes and large wooded area. Area 4 is located 300 m from the nearest building, and the first variant 230 m. Alternatives W1 and W4 are separated by only minor wooded and bushy areas from the buildings.

All selected WTP's locations are presented in the figure 2.

Figure 2. Small wastewater treatment plant sites

Source: Geoportal, 2018.

Results of the research

According to Saaty's methodology (Saaty, 1980, 1996, 2001, 2008), using 9-point scale presented in table 1, criteria were pairwise compared, as well as variants for each criterion. Table 2 shows analysed alternatives priorities.

Table 2. The value of priorities for variants

Criterion (weight)	Variants			
	W1	W2	W3	W4
Cr1 (0.04)	0.002	0.009	0.017	0.017
Cr2 (0.08)	0.024	0.006	0.034	0.003
Cr3 (0.078)	0.011	0.003	0.008	0.034
Cr4 (0.358)	0.035	0.086	0.154	0.154
Cr5 (0.175)	0.011	0.030	0.075	0.017
Cr6 (0.112)	0.012	0.048	0.048	0.024
Cr7 (0.157)	0.068	0.034	0.017	0.017

Source: author's own work.

Based on the alternatives pairwise comparison, priority for economic criteria was the highest (over 50%). The second most important criteria were social (Cr6 and Cr7), of almost 30% of participation.

Alternatives analysed with respect to each criteria were pairwise compared and the variants hierarchy was obtained as a result. The sequence was as follows: W3>W4>W2>W1. The optimal variant was W3, with large advantage over the second best variant – W4 (figure 3).

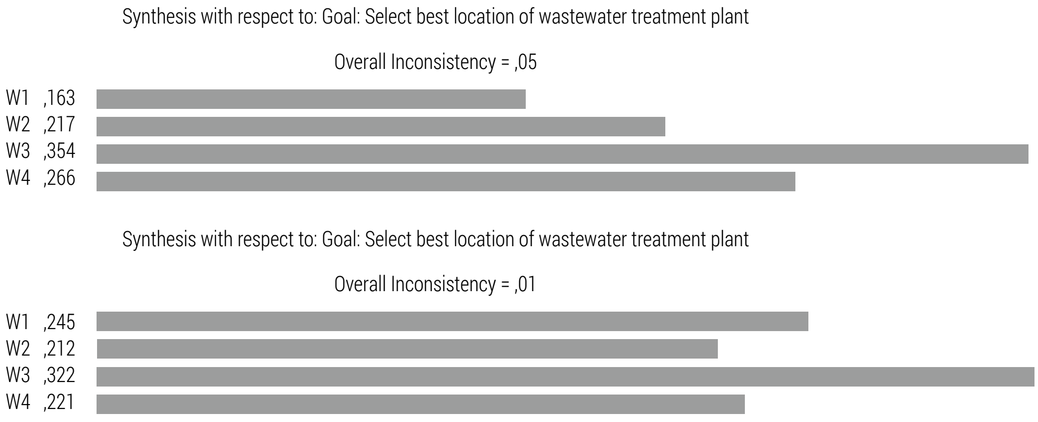

Figure 3. AHP final results with regard to different (above) and equal (below) criteria weights Source: author's own work.

Analysis for equivalent alternatives importance were also prepared, however the final result was the same. Criteria weights alignment affect W1 priority increase (figure 3).

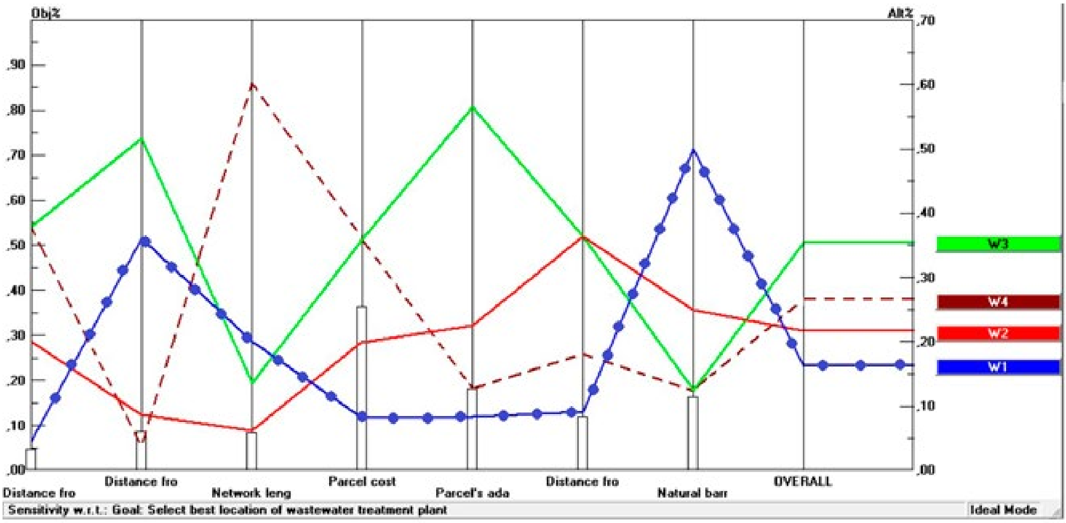

Figure 4. AHP final results with regard to each criterium importance

Source: author's own work.

As it can be seen in the figure 4, high variant 3 advantage over other alternatives was due to criterion 2 (distance from the sewage receiver) and 5 (parcel adaptation cost). The second best result was characterized by very high criterion 3 impact – network length needed to connect WTP to the sewage system.

All presented results were prepared in Expert Choice 11 software.

Conclusions

Due to the flexibility, simplicity, and possibility to compare the qualitative and quantitative factors the method invented by Saaty has been applied in many different fields. In this work, the AHP method was used to compare the alterative locations of a small wastewater treatment plant in a rural commune. The study included analysis of seven criteria and four variants.

- Due to many factors affecting the sewage treatment plants location selection, it is necessary to carefully analyse the possible solutions.
- AHP analysis allowed to easily compare many alternative solutions to the problem for many criteria.
- The best sewage treatment plant's location in accordance with the results of the analysis was variant 3, mainly due to the low costs of plot adaptation for the investment needs and distance from the sewage receiver.
- Equalization of the criteria weights did not affect the final variant choice.

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The contribution of the authors

Iwona Skoczko – 50%.

Katarzyna Oszczapińska – 50%.

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