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An economic analysis of the reservoirs reclamation methods in the Kłodnica River catchment

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Abstract: Reclamation and rehabilitation of water reservoirs is particularly important for their functioning and fulfilment of their economic, social, natural and other functions. The paper presents a case study of the ex-ante economic analysis used to determine the most suitable reservoirs reclamation method from the pre-selected methods (such as: hypolimnion removal and silt dredging) for the three reservoirs in the Kłodnica River catchment situated in Silesia Province. The presented results and their discussion are of practical importance in order to select a particular way of improving the water quality of the reservoirs as well as contribute to the development of methods of assessing the economic efficiency of water reservoir reclamation in Poland.

Keywords: economic analysis, reclamation, water reservoirs, Kłodnica River

JEL codes: Q50, Q51

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1. Introduction

Reclamation of water reservoirs, especially ones constructed with the use of dams, which are positioned on rivers and which are part of their flow, is important for the catchment

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ecosystem as a whole. The reclamation of reservoirs can be understood as their remediation, rehabilitation or renewal of the given ecosystem. As it is hardly possible to bring back reservoirs with persistent high anthropogenic pressures to the pristine natural conditions, the final desired effect of the reclamation is thus defined by a set of goals and criteria, such as the level of water quality defined by a set of parameters. Also, the economic feasibility of the solution is of a great importance and it is crucial for the implementation of a particular reclamation method. The selection of adequate methods is getting wider, as new, innovative, better suited for the particular conditions of the ecosystems and effective methods for improvement of water quality in reservoirs are developed.

The analysis presented in the paper was conducted by the author within the study concerning the elaboration of the programme for reclamation of the reservoirs in Kłodnica River catchment (RZGW, 2016), undertaken by the Regional Water Management Board in Gliwice. The research question for the paper is whether hypolimnion removal or silt dredging would be the most financially and economically efficient reclamation method for the analysed reservoirs in the Kłodnica River catchment and under what conditions.

In the paper, the case study area of Kłodnica River catchment is presented. Then the method for cost-effectiveness assessment of reclamation solutions is described. Next, the possible rehabilitation methods and assumptions, as well as the results of the assessments are presented, followed by the discussion of the results and the conclusions.

2. Reservoirs in the Kłodnica River catchment

The Silesia region in the South of Poland, where the Kłodnica catchment is situated, features high urbanisation and industrialisation level. These high anthropogenic pressures have a substantive impact on the water quality in the analysed three reservoirs. At the same time the river and the reservoirs constitute a popular destination for recreation for the local as well as regional inhabitants. Therefore, they are both under a threat to the water quality and pressure for its purification exits. The identified need is the effective improvement of the ecological status of the reservoirs. In response to this need, the Regional Water Management Board in Gliwice decided to prepare a programme for the reclamation of the reservoirs in the Kłodnica catchment (RZGW, 2016), in which the solutions leading to water quality improvements in the reservoirs are proposed. They all accumulate about 140 Mio m3 of water at the area of 10 km2, of which almost 6 km^2 belongs to Dzierżno Duże reservoir constructed in the year 1963, whereas 1.3 km^2 belongs to the oldest Dzierżno Małe reservoir (founded in the year 1938) and 2.7 km^2 – to the youngest Pławniowice reservoir (founded in year 1979).

The analysis of the spatial development around the reservoirs depicts the types of ecosystems as well as the types of economic activities, which will be directly affected by the improvement of the water quality in the reservoirs. Agricultural land occupies about 12% of the buffer areas that are closest to the reservoirs. Cleaned reservoirs could perform economic functions by supplying water for irrigation. Green areas and forests occupy about 32% of the areas. Reclamation of the reservoirs will favourably affect these ecosystems by improving the state of flora and fauna. Recreational areas (sports and recreation services, tourism and recreation, surface water and waterways) occupy 17% of the analysed area, while services and housing account for the 10% the area. Reclamation will increase interest in these areas, and thus also increase the value of the land and business income. The potential demand for recreation due to the proximity of the urban agglomeration is high. All these aspects constitute potential economic benefits from the reservoirs reclamation.

The undertaken efforts to improve the quality of water in the reservoirs indicate that residents and many organizations would like to reclaim the reservoir and that they see the prospective benefits in doing so. (Dzierżnu..., 2015)

3. Cost-effectiveness method used

Performance assessments can be conducted using methods such as Cost-Effectiveness Analysis (CEA). The common feature of cost-effectiveness indexes is to compare the costs of different solutions taken into account, by the assumed desired effect(s) they all bring. Hence, while using the CEA analysis to evaluate and compare the economic efficiency of the projects, it is important to choose the outcome indicators for which cost effectiveness is calculated. CEA is most often used when monetary evaluation of the effects of the proposed solution is impossible.

In the analysed case study, the desired effects for the reclamation of the reservoirs are defined as the following: limiting the effects of eutrophication, which will lead to increased water transparency, increased concentration and amount of oxygen in the hypolimnion, and will initiate the process of oligotrophication of the reservoirs by removing phosphorus compounds from the ecosystem. Taking these desired effects into account, the purpose of economic analysis is to evaluate different methods of reservoirs reclamation in terms of their cost effectiveness. The analysis includes the financial costs borne by the investor and the total costs (including environmental and social costs) of the proposed methods. Dynamic Generation Cost (DGC) method was used for the ex-ante evaluation of the cost-effectiveness of proposed reclamation actions. In addition, the value of environmental costs has been assessed.

Dynamic Generation Cost shows the discounted cost of obtaining a unit of social or ecological effect. This way it takes into account the variable value of money over time (discount) on both the costs and the results sides (previous results are given a bonus over the later). The obtained index is an indicator to the present value of the cost of obtaining a unit of the result. The dynamic unit cost index is calculated as follows:

$$DGC = p_{EE} = \frac{\sum_{t=0}^{t=n} \frac{KI_t + KE_t}{(1+i)^t}}{\sum_{t=0}^{t=n} \frac{EE_t}{(1+i)^t}}.$$

- KI_t – investment costs incurred in a given year;
- KEt – operating costs incurred in a given year;
- i – discount rate;
- t – year, takes values from 0 to n, where 0 is the year in which the first costs are born and n is the last year of installation operation;
- EEt – ecological effect.

The dynamic unit cost is equal to the price that allows obtaining a discounted revenue equal to the discounted cost. In other words, it can be said that the DGC shows the technical cost of obtaining a unit of ecological effect. This cost in the conducted analysis is expressed in PLN per unit of ecological effect. Rączka (2002)

4. Chosen reservoirs reclamation methods

Two reservoirs reclamation methods, the most promising in the multi-criteria qualitative pre-selection, were selected for the final economic analysis, namely: hypolimnion removal with the use of Olszewski pipe and silt dredging with the use of Watermaster Classic IV.

These methods differ from each other in terms of different kinds of environmental impacts they cause and the intensity of the impacts, they interact positively and / or negatively on particular elements of the environment and ecosystems. These aspects will be analysed in the subsequent chapter. Moreover, the methods constitute different technological solutions, from the constructional point of view, reclamation processes taking place and the amount of energy used. Additionally, the level of capital investment and operating expenditures, needed in the lifetime of the solutions implementation, vary in both analysed methods. Last, but not least, the period during which the planned reclamation effect is achieved distinguishes the methods. In the silt dredging the effect of clean water is achieved immediately, while in hypolimnion removal with the use of Olszewski pipe it takes a while before the pollutants are removed from the reservoir. Therefore, as it was mentioned, the choice of a particular reclamation method is the matter of the goal or the effect which are desired.

5. Assumptions and results of Cost-Effectiveness Analysis of the selected reclamation methods

The main assumptions in the analysis were the following:

- The period of analysis is 30 years (until 2027), as the expected and estimated effect will be reached for all reservoirs in this period.
- Fixed prices from year 2016 were used.
- The year of completion of the investment is the base year for the analysis. It is the year 2017 for the removal of hypolimnion in all the reservoirs and for the silt-dredging – the year 2022 in the reservoir of Dzierżno Duże, the year 2018 in Dzierżno Małe and 2017 in Pławniowice.
- Discount rate was assumed at 3.5% and the sensitivity analysis of the obtained results on the discount rate was performed by simulating its change by 0.5 ppt.
- Transfer payments were eliminated.
- The investor did not make any financial gain (revenue) as a result of the reclamation.
- Investment expenditures for hypolimnion removal were calculated as the sum of material costs, labour costs and investment preparation costs (20% of total investment costs), including design and documentation costs, and studies and analyses.
- Investment expenditures for sludge removal were calculated as the sum of: costs of execution, sludge storage costs and investment preparation costs (20% adequately).
- Operating costs were estimated as the sum of the costs of monitoring, operation and repair costs. Both methods do not actually generate operating and maintenance costs. More details can be found in RZGW (2016).

The investment cost in hypolimnion removal with Olszewski pipe constitutes only 1.1% to 2.5% of the costs of silt dredging with the use of Watermaster Classic IV. The results obtained with the use of the cheaper method are sufficient for the investor, as some of the final result of the methods are the same or similar, such as removal sediments or P-PO4 (phosphorus) loads. Table 1 presents the comparison of discounted costs for the effect of removal of the unit of loads [in PLN per Mg per year of removed P-PO4 (phosphorus) loads] for various discount rates.

Table 1. Sensitivity analysis of DGC indexes for the effect of removal of loads [in PLN per Mg per year of removed P-PO4] for the various discount rates

Reservoir	Method	DGC by the discount rate		
		3%	3.5%	4%
Dzierżno Duże	hypolimnion removal	13 737.40	13 908.64	14 081.09
	silt dredging	454 421.00	453 750.09	458 839.16
Dzierżno Małe	hypolimnion removal	1 664.57	1 670.52	1 676.72
	silt dredging	33 468.47	33 610.87	33 753.81
Pławniowice	hypolimnion removal	21 349.15	21 401.56	21 456.63
	silt dredging	139 644.81	140 285.29	140 926.75

Source: based on (RZGW, 2016)

As it can be concluded from Table 1 the silt dredging is more expensive than hypolimnion removal, regardless of the size and conditions of the reservoir. The smaller the size of reservoir, the less expensive per unit of the removed loads the silt dredging would be. The changes of the discount rates (by 0.5 ppt.) are not important for the final financial decision as they alter the outcomes insignificantly.

In the event of inflow of additional loads to the reservoir, e.g. due to flood, consequently the removal of larger loads with hypolimnion will occur and consequently the cost per unit of removed loads will be even lower.

The environmental and social effects for the reservoirs can be presented as an increase in ecosystem services after the reclamation as presented in Table 2. As indicated they are linked to the social and economic benefits.

Table 2. Predicted changes in individual categories of ecosystem services after the reservoirs' reclamation

Categories of ecosystem services	Ecosystem services	Changes and their economic and social importance
Provisioning	Food (fish, plants)	Increase in biodiversity, improvement of living conditions of animals, including fish. Positive impact on fish business and fishing, recreation and tourism.
	Water (drinking, irrigation, transport, recreation, etc.)	Reclamation of the Pławniowice reservoir has improved the water quality to a state that it can be used for municipal purposes. In the other reservoirs, improving water conditions will increase their recreational attractiveness. In the case of the Dzierżno Duże reservoir, improvement of the quality of water released to the Gliwice Canal may have a beneficial effect on the water quality of the canal. Increased intensity of recreational activities, which is important for residents, leisure centres, etc. Possibility of using water for irrigation.
Regulating and maintenance	Neutralization of waste, toxic and other substances (by fauna and flora and by ecosystems) -> water purification and air quality maintenance	Reclamation of the reservoirs will increase their resistance to eutrophication and will increase the capacity, viability and efficiency of ecosystems, so that the performance of their function will be improved.
	Biological pest and disease control	Improving the oxygen conditions in the reservoirs will limit the occurrence of anaerobic processes and may reduce the pressure of parasites on fish and reduce the risk of fish diseases. Positive impact on fish business and fishing.
	Reduction of greenhouse gases emissions	The oligotrophication of the reservoirs, mainly the reduction of phosphorus abundance, will improve the oxygen conditions and thus reduce the anaerobic processes in the bottom sediments and in turn significantly reduce the methane release.
Cultural services	Recreation	Reclamation of the reservoirs will significantly increase their attractiveness and the attractiveness of their surroundings.
	Tourism	Positive impact
	Ecotourism	Positive impact
	Aesthetic value	Very positive impact, the reduction of phytoplankton blooms.
	Scientific value	New areas for research concerning response of manmade reservoirs ecosystems to the reclamation method used.
	Cultural value	The ecological awareness of the community, which will appreciate the improvement of ecosystems, should increase.

Source: own elaboration based on categorization provided by Millennium Ecosystem Assessment, The Economics of Ecosystem and Biodiversity and the Common International Classification of Ecosystem Services (MEA, 2005).

As shown by the example of application of hypolimnion removal with Olszewski pipe method in the Pławniowice reservoir, the introduction of the hypolimnion water outflow significantly increases water transparency, reduces algal bloom intensity, improves aerobic conditions and increases the ecosystem resistance. (Kostecki, 2004) Also, improvement of water quality in the reservoirs reduces costs of water treatment. The difference in the coefficients of payments for water treatment of inland surface water is 2.2 as the coefficient for water not subjected to treatment is 2.8 and the coefficient for water subjected to treatment processes equals 0,6. (Rozporządzenie..., 2015) Moreover, as a result of the reclamation the biodiversity increase can be observed of both plants and animals.

This qualitative assessment can be monetized with the use of various methods. However, the literature on how to estimate environmental benefits and costs is still not perfect enough to give decision makers quantifiable and reliable information they need. (Bateman et al., 2010, Brouwer et al., 2013) The average monetary value of lake ecosystem services is estimated at 8 498 USD per ha (33 508 PLN),[1] of which 5 445 USD (21 470 PLN) per ha (64%) is associated with runoff regulation, 2 117 USD (8 348 PLN) per ha (25%) is attributed to water supply, 665 USD (2 622 PLN) per ha is associated with sewage treatment, 41 USD (162 PLN) per ha (0,05%) is attributed to food production and finally 230 USD (907 PLN) per ha (2.7%) is related to recreation (Costanza et al., 1997). Locally, the economic value of ecosystems is greatly dependent on the state of the environment and consequently on the quality and quantity of ecosystem services provided and the functions performed by the reservoirs.

6. Discussion of the results

The analysis of similar case studies presented in the literature indicates the significant value of the above-mentioned benefits generated by the implementation of rehabilitation projects. In the case of Lake Delevan (USA), the area of 1.5 km2, the annual benefits from improving water quality through reclamation of the reservoir was estimated at 77 million USD (304 million PLN), which exceeded 50 million USD (197 million PLN) of investment, created 812 jobs, the was responsible for the increase of aggregated land value by 99 million USD (390 million PLN) in the years 1987-2003. Between the years 1987-1995 the value of the shoreline land of the lake, based on the hedonic pricing method, increased by 354%, and

[1] All the estimates are presented in average weighted exchange rates of 2016 year, the year of the analysis.

in the following years to 2003 by a further 22%. (What..., 2005) In the case of the lakes of Beulah and Lauderdale (USA), lakefront values increased by 222% in the years 1987-1995 and by a further 57% till 2003. Kashian (2006) Brouwer et al. (2015), based on 86 worldwide analysed case studies, estimates that the average willingness to pay for river rehabilitation projects is 66.5 EUR (290 PLN) per household per year in Europe, 64 EUR (279 PLN) in Asia and 76.9 EUR (335 PLN) in America Northern. The above mentioned cases possess an illustrative value, but it is not possible to directly transfer the indicated benefits.

The obtained results are very sensitive to the length of the time period of the analysis as well as the implemented discount rate. The discount rate, being also a long-term return on investment, is crucial for comparing the costs and benefits of different projects over time. It is usually advisable to take lower rates for a longer time horizon in order not to underestimate the current value of the property and not to transfer unjustifiable high costs to future generations. The results of application of various discount rates can be seen in the works of Dubel, Trela (2014) and Trela, Dubel (2014).

Cost-efficiency indicators tell us about the cost per unit of product or result. Under the CEA, it is not possible to assess the effectiveness of the project in absolute terms, and therefore the analysis cannot be used to determine the effectiveness or ineffectiveness of the project. The advantage of this method lies rather in its ability to compare solutions in terms of their costs.

The DGC method allows assessing the cost-effectiveness and relative economic effectiveness of projects for which reliable result indicators can be obtained. The DGC method can be the basis for determining the economic efficiency of all projects for which the evaluation of results is difficult or costly, and the result indicators are typical and comparable between projects. This method is often used to evaluate projects related to the environment.

In the analysed case study, an important condition for reaching a sustainable environmental effect, while applying the proposed reclamation methods, is the reduction of inflow of pollutants to the analysed reservoirs.

7. Conclusions

Two promising methods of reclamation and rehabilitation of reservoirs were compared using the Dynamic Generation Cost index. The hypolimnion removal with the use of Olszewski pipes and silts dredging with the use of Watermaster Classic IV. Among them the hypolimnion removal was proved to be by far cheaper and a very cost-efficient method of reservoirs reclamation. However, the durable effect of water quality improvements can be sustained only by the reduction of inflow of pollutants to the analysed reservoirs.

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ANALIZA EKONOMICZNA WYBRANYCH METOD REKULTYWACJI ZBIORNIKÓW W ZLEWNI RZEKI KŁODNICY

Streszczenie

Rekultywacja zbiorników przypływowych i zaporowych jest szczególnie istotna dla ich funkcjonowania i pełnienia przez nie funkcji ekonomicznych, społecznych, przyrodniczych i innych, do których zostały powołane. Artykuł prezentuje studium przypadku zastosowania analizy efektywności ekonomicznej do oceny ex-ante wybranych metod rekultywacji (usuwanie hypolimnionu i wydobywanie osadów) dla trzech zbiorników przypływowych w zlewni rzeki Kłodnicy w województwie śląskim. Zaprezentowane wyniki i ich dyskusja mają znaczenie praktyczne, służące wyborowi konkretnego sposobu rozwiązania poprawiającego jakość zbiorników, jak również stanowią wkład w rozwój metod oceny efektywności ekonomicznej rekultywacji zbiorników wodnych w Polsce.

Słowa kluczowe: analiza ekonomiczna, rekultywacja, zbiorniki zaporowe, Kłodnica

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