



Assessing Economic Feasibility of Managed Aquifer Recharge Schemes: Evidence from Cost-benefit Analysis in Poland

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Highlights

- Managed aquifer recharge (MAR) schemes are promising solutions in water management.
- It is important to ensure the economic feasibility and viability of MAR schemes.
- Cost-benefit analysis (CBA) is a widely used approach for the economic feasibility assessment of MAR projects.
- Our findings support the importance of the MAR scheme's non-use benefits.

Abstract

The accelerated growth of water demand globally calls for promising solutions in the field of water management. Managed aquifer recharge (MAR) systems are among the solutions that are capable of increasing water supply and improving water quality through natural attenuation processes. Along with hydrogeologic considerations and institutional feasibility assessments, economic analysis is essential when evaluating MAR projects. This study is the first one to provide an economic feasibility assessment of a MAR scheme in Poland by performing a cost-benefit analysis (CBA) combined with a contingent valuation study to identify the willingness-to-pay, sensitivity analysis to address uncertainty regarding the realisation of benefits and costs together with expert assessment of socio-economic risks associated with the MAR scheme implementation. The results suggest that the total economic value of the MAR scheme's extension (which includes both use and non-use benefits) exceeds the costs of putting this system in place and maintaining it. This paper can contribute to the existing literature as a practical example providing the base for economic assessment and policy considerations of future sustainable water management projects.

Keywords MAR scheme · Cost-benefit analysis · Environmental benefit · Willingness-to-pay · Risk · Sensitivity analysis

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1 Introduction

Increasing global water demand has lately been amplified by the change in climatic conditions, with Central Europe being noticeably affected¹. These challenges are even more profound for Poland, since its water resources are among the lowest in Europe (Kubiak-Wójcicka 2021). Thus, water management initiatives have come to the forefront, aiming to address these challenges and facilitate the protection of scarce water resources. Among water management projects, managed aquifer recharge (MAR) systems are increasingly being used to maintain, enhance, and secure the balance of groundwater systems under pressure (Dillon et al. 2019; UNESCO 2022).

Excess water supply from rainfall, flooding, water treatment plants, rivers or desalinated seawater can be intentionally recharged into the aquifer for subsequent recovery or environmental benefits (Dillon et al. 2009). MAR schemes can contribute to an increased water quantity and supply security (e.g., for irrigation or human consumption), the reduction of costs of providing or storing water (e.g., external water purchase, above-ground storage, desalination plants), and the improvement of water quality through natural attenuation processes (Gale 2005). Moreover, MAR schemes can potentially be used for groundwater conservation in the presence of increased drought risk (Tran et al. 2020) and can also offer the benefit of reducing evaporative water losses (Vanderzalm et al. 2022).

Despite the hydrological advantages that MAR schemes can offer, it is nevertheless essential to ascertain their economic sustainability. To achieve this, the net benefit of MAR scheme implementation and further operation must be positive. Thus, along with technical, social or policy-related considerations, economic analysis is essential to assessing the feasibility of MAR projects.

In most cases, an economic evaluation of water projects aims to determine whether their benefits justify anticipated costs and/or compare alternative options (Rashid and Hayes 2011; Wang and Corbett 2021). The first objective of net benefits is supported by economic efficiency analysis, mainly cost-benefit analysis (CBA), while cost-effectiveness analysis is used to meet the second objective where the net benefits of alternative options are considered. The latter approach is based on establishing the minimum investment for the best possible performance among the number of alternative options/improvements (Rashid and Hayes 2011). Cost-effectiveness analysis is mainly used in cases where the reliable estimation of benefits is infeasible. However, its core limitation is that all alternatives can be ranked without affirmation that any of them are worth implementation (Maliva 2014).

CBA is among the most frequently used approaches for assessing the economic feasibility of MAR projects (Maliva 2014) and water projects in general. CBA assesses an investment's economic feasibility and profitability by comparing all the resulting benefits and costs (private and social, direct and indirect, tangible and intangible). The criterion to approve or not the construction of MAR systems under CBA is that the total economic value of benefits should exceed the total costs. In the case of CBA, the main challenges are the estimation of accurate benefits values (as they should incorporate non-use values) and the data-intensiveness of the method.

This study aims to assess the economic feasibility of extending an existing MAR scheme in Poland by conducting a CBA. The applied methodology not only allows the evaluation of the financial sustainability of the MAR project but also the incorporation of the MAR

¹The EU Water Framework DirectiveThe EU Water Framework Directive.

system's environmental benefits. Socio-environmental benefits are captured through non-use values of water for drinking water users (existence, bequest and altruistic values). In the context of this study, these values were revealed via a stated preference technique, the contingent valuation method. Another important part of our methodology deals with accounting for uncertainty regarding the realisation of benefits and costs. To address uncertainty, we used sensitivity analysis and the expert assessment of socio-economic risks associated with the MAR scheme. As highlighted in our previous work, few publications are so far available that focus on the economic assessment of MAR schemes (Imig et al. 2022). Consequently, this study aims at contributing to the advancement of MAR economic feasibility assessment, which also supports the implementation of MAR methodologies for sustainable and resilient water resources management, such as proposed by the European Union in the Green Deal².

The rest of the paper is organised in the following way: in Sect. 2, we describe the case study area, outline the methodology used in this research and provide a description of the data collected. Next, the results obtained are reported and discussed in Sect. 3. Finally, in Sect. 4, we provide some conclusions by presenting an overview of the study outcomes and how they can be of practical relevance for policy-makers.

2 Materials and Methods

2.1 Case Study Area

The case study area, the Świerczków well field, is in south-eastern Poland, in the city of Tarnów (Fig. 1). The well field consists of 17 wells, of which two are temporarily unexploited due to the deterioration of water quality in these wells because of the age of well W-22 and the well's location too close to the infiltration ditch (W-2a), which has periodically led to bacteria in the water. The MAR system, consisting of infiltration ditches and induced bank filtration (IBF), is already in place and has been operating since the 1960s, supplying Tarnów and the surrounding towns with drinking water. Most of the wells are additionally recharged by the system of infiltration ditches, the IBF is only a secondary recharge method, partially supplying three wells located very near the Dunajec river (IBF wells in Fig. 1). Natural rainwater infiltration into the aquifer is a minor value. Based on the studies performed in the area³ regarding hydrological, hydrogeological and geological criteria outside the Tarnów region, both MAR methods (infiltration ditches and IBF) could be implemented on about 13% of the Dunajec river catchment area (Fig. 1). Suitable conditions for the location of IBF and infiltration ditches are found, among others, in the region's largest towns such as Nowy Sącz (84 000 inhabitants) and Nowy Targ (33 000 inhabitants).

Given that MAR systems can be implemented in the case study area, the next important step is to investigate the economic feasibility of expanding the existing MAR system, which will increase the efficiency of the well field and improve the native groundwater quality. Since there is a large nitrogen plant directly near the study area, which puts a shallow quaternary aquifer at serious risk of potential contamination, it is vital to guarantee groundwater

² A European Green Deal.

³ Studies conducted within DEEPWATER-CE project: <https://www.interreg-central.eu/Content.Node/DEEPWATER-CE.html>.

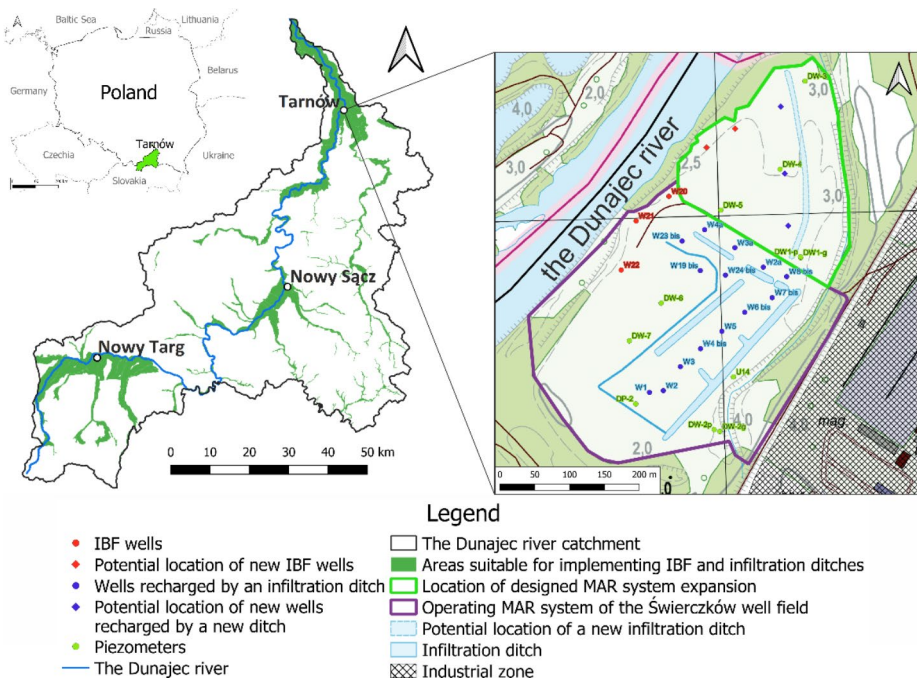


Fig. 1 Research area, presented on a national, regional, and local scale

quality in the area. Furthermore, in the future, water supply reliability must be increased to tackle such challenges as decreasing groundwater levels due to climate change (Fienen and Arshad 2016). Groundwater derived from the MAR scheme can be used for drinking purposes in the Tarnów conurbation (about 108,470 inhabitants in Tarnów city and a population of 269,000 inhabitants in the metropolitan area). This makes it necessary to ensure the groundwater’s safety and good quality, compliant with drinking water standards.

2.2 Cost-Benefit Analysis

Cost-benefit analysis is a method that assesses the economic feasibility, profitability and sustainability of a project by comparing all the relevant benefits and costs that are put on a common temporal footing:

$$\sum_{t=1}^T \frac{B_t - C_t}{(1 + r)^t} \tag{1}$$

where t: is time,

T: time horizon.

B_t : future expected streams of benefits,

C_t : future expected streams of costs,

r: discount rate.

In the field of water resources, Brouwer and Pearce (2005) provide an overview of the state-of-the-art in CBA in water resources management throughout Europe and North America, while Job (2021) comprehensively discusses CBA of groundwater policy and projects with practical examples from case studies. Regarding MAR schemes, Maliva (2014, 2020) outlines the basic principles of the economics of MAR, the evaluation of its economic feasibility using CBA, and discusses the challenge of monetising benefits.

2.2.1 Cost Analysis

Two main sets of information are needed for the CBA performed in this study: cost and benefit information. The main groups of initial investment and capital costs associated with the extension of the MAR scheme include: (i) investigation costs (including hydro-geological and geophysical surveys, physicochemical analyses of water, modelling studies, forecasting simulations, etc.); (ii) the cost of constructing the wells (including drilling a borehole, installing a well, conducting pumping tests, and geodesic surveying); (iii) the cost of constructing the piezometers (including drilling a borehole, installation of piezometer and protective casing), (iv) costs related to the infiltration ditch construction (excavation and ground levelling), and (v) the cost of connecting new wells and a ditch to the existing syphon system. The project timeline foresees that all the necessary investigations and installation of the piezometers can be conducted during the project's first year, while the wells and infiltration ditch construction can be implemented in the second.

Since the MAR scheme is already operating and historical data exists on the operation and maintenance costs, related costs associated with the expansion can be calculated using the ratio of the size of the expansion to the size of the current MAR system. The current MAR facility includes 17 working wells and three infiltration ditches, while the expansion being considered is planned to consist of five extra wells and one additional ditch. Thus, all the operation and maintenance costs (except storage costs⁴) have been multiplied by 0.3⁵ to obtain estimates of the annual operation costs of the MAR expansion. Average values and the range of the annual operation, maintenance and management costs, along with the capital costs, are presented in Table 1.

2.2.2 Benefit Analysis (direct benefits)

The inhabitants of the city of Tarnów and the surrounding towns supplied with drinking water by Tarnów Waterworks (TW), a major water supplier in the area, are the main beneficiaries of the proposed expansion of the MAR scheme. The main direct benefit of the expansion is the increase in the available water resources for the city and nearby towns. Besides that, the local population will also experience an environmental benefit. The improvement in groundwater quality mainly occurs because of the dilution effect: mixing groundwater of poor quality with water from the MAR. The effectiveness of the dilution process allows the direct injection of water into the network, since the water pumped from the wells no longer requires treatment. Thus, the MAR scheme extension can help reduce the risk of

⁴ Additional storage is not planned.

⁵ We have historical data on maintenance costs for 17 working wells and 3 infiltration ditches, since we need an estimate of operation costs for 5 wells and 1 ditch we used factor 0.3, which is the average of two ratios ($5/17=0.29$, $1/3=0.33$).

Table 1 Costs and direct benefits associated with the MAR scheme's expansion

	Value
Cost group, average value in € (range (min-max) in €)	
Initial investment-Capital costs	159,841 (146,729 – 172,953)
Investigation costs	15,059 (12,848 – 17,270)
Cost of wells	25,751
Cost of piezometers	6,853 (6,798–6,908)
Cost of infiltration ditch	51,678 (46,332 – 57,024)
Cost of connecting new wells and ditch to the existing system	60,500 (55,000–66,000)
Annual operation and maintenance costs	148,812
Raw water costs	21,315
Cost of extraction and distribution	76,665
Labour costs	13,299
Electricity costs	23,876
Amortisation costs	7,827
Post-treatment costs	2,859
Regulatory testing cost	2,970
Indicators used for calculating the direct benefits	
Average total drinking water demand of the city of Tarnów and surrounding towns in 2019–2020, m ³	7,986,713
Share of water from the existing MAR scheme in the total household water consumption in the city of Tarnów and surrounding smaller towns, %	22
The annual amount of available water resources due to the expansion of the MAR scheme, m ³	509,106
Price of drinking water supply, € per m ³	0.70
Assumed annual growth rate for the price of water supply (in the first 3 years), %	3–4.5
Revenue of TW from the MAR extension, 1000 €	1st year 371 2nd year 382 3rd year 394

Source: Data provided by Tarnów Waterworks

groundwater contamination due to the industrial zones in the area, contributing recharge to the Świerczków well field.

The direct use benefit of the MAR scheme expansion is estimated as a product of the annual amount of the water resources available due to the expansion and the price currently being paid by the local population for their drinking water supply (considering its gradual increase during the first three years of the project (estimated by TW) and stable price afterwards). The existing MAR scheme covers approximately 22% of the potable water produced by TW. Expanding the existing MAR is expected to increase this share by approximately 6%. The calculated values of direct benefits from the expansion are presented in Table 1.

2.2.3 Net Present Value

Following CBA literature (Arshad et al. 2014; Rupérez-Moreno et al. 2017) relevant to our study, we use the net present value (NPV) as a profitability indicator to assess the economic feasibility of the MAR scheme. NPV is a sum of private and socio-environmental net cash flows (the difference between the present value of benefits and the present value of costs over a selected time horizon):

$$NPV = -k + \sum_{t=1}^T \frac{NCF_p}{(1+r_f)^t} + \sum_{t=1}^T \frac{NCF_s}{(1+r_s)^t} \quad (2)$$

where k : initial investment cost,

t : time,

T : time horizon.

NCF_p : private net cash flow,

NCF_s : socio-environmental net cash flow,

r_f : financial discount rate,

r_s : social discount rate

NPV is the sum of the discounted value of the stream of benefits (in our case, the direct, indirect and non-use values of MAR schemes) minus the present value of future costs and initial capital costs. Among the direct use value of the MAR scheme is an increased supply of water for drinking by making use of periodic excess surface water supplies and preservation or improvement of water quality, while the indirect use value of the MAR system is reflected in being a buffer against drought and variable climate. Finally, non-use values can be captured by the willingness to pay for water in a conserved or sustainable use state, but the willingness to pay is unrelated to the current water use.

According to literature and local expert suggestions, the project lifespan was specified as 30 years (Ross and Hasnain 2018; Dashora et al. 2019; Arschad et al. 2014). Therefore, the values of discount rates were selected following the European Commission's benchmark⁶, namely the financial discount rate of 4% (for costs and direct benefits) in real terms for 30 years reference period for water supply projects and the social discount rate of 5% (for non-use benefits).

A survey was developed and disseminated among the local community in Tarnów to find out the maximum amount of money that people would be willing to pay to have a stable supply of drinking water to estimate both use and non-use (in our case, socio-environmental) benefits, to ensure its proper quality (no chemical contamination) and to improve the groundwater body's ecological status.

2.3 Details on Survey Design and Implementation

CBA that accounts for environmental aspects can be applied to assess the feasibility of water projects that have special environmental features and include issues of water quality and quantity (Maliva 2014). It is also important in water management studies to conduct a social CBA that accounts for social profitability and inter-generational sustainability by incorporating the total economic non-use value of water projects in the analysis. Empiri-

⁶ Available online: https://ec.europa.eu/inea/sites/inea/files/cba_guide_cohesion_policy.pdf.

cal evidence suggests that the society is interested in not only use (increased water supply, improved quality of water) but also significant non-use values (existence, bequest and altruistic values) (Damigos et al. 2017).

Thus, the survey for this study was designed to reveal the total economic value (use and non-use values) of MAR schemes using a contingent valuation method, which is a widely used tool in studies aimed at assessing the total economic value of MAR systems (Damigos et al. 2017; Rupérez-Moreno et al. 2017). Contingent valuation is a survey-based method to determine an individual's willingness to pay (WTP) or willingness to accept compensation for a good or service, such as improved urban (potable) water quality and quantity (Genius et al. 2008; Hatton MacDonald et al. 2010; del Saz-Salazar et al. 2016; Schinck et al. 2020). When designing the survey, we followed the paper by Damigos et al. (2017), in which the authors aimed to reveal the economic value of MAR via a contingent valuation study in Italy.

In developing the questionnaire for the drinking water MAR system in Poland, we followed the concept of "general specific," i.e., we started with general questions on the state of the environment and then narrowed down the questions to address more specific issues. In the questionnaire, the first part contained questions on general society knowledge regarding problems related to groundwater quality and quantity in the area of interest or main concerns and prevailing pressures on groundwater sources. In addition, the respondents were asked to self-assess the household impact on groundwater, whether they felt responsible for contributing to the protection and preservation plans for groundwater, and whether they were aware of the currently operating chemical plant in their region.

Questions gradually became more specialised in the second part of the questionnaire, which deals with the WTP for the proposed MAR scheme expansion. The second part started with a brief description of the MAR project, outlining its objectives, main benefits and the need for financial contributions to implement the expansion. The description was followed by questions on the preferred way of funding the proposed plan and the maximum amount the respondent would be willing to pay per month. Finally, a set of options for these maximum amounts was proposed based on the average drinking water price in the area. If respondents chose not to contribute to the proposed plan, they were asked to select the reason for such a decision. If any amount of financial support was provided, the respondent was asked to distribute it to the distinct categories of benefits that the MAR scheme yields (use and non-use benefits).

The concluding part of the questionnaire included questions on the respondent's profile, namely demographic (gender, age, number of children) and socio-economic questions (educational level, employment status, income level). The questionnaire also included a section that reveals the respondent's concerns regarding the safety of the drinking water supply from the MAR system. To conduct the survey, questionnaires were distributed both in paper form and online via e-mail for self-filling. Along with these conventional types of survey distribution, a social media ad (on Facebook) was used to boost the post with a survey description and link. This ad aimed to increase awareness among the population being targeted (the citizens of Tarnów and surrounding areas).

3 Results

3.1 Survey Results

The total number of complete responses obtained was 51, with a good balance of socio-demographic characteristics; overall, the sample is reasonably representative of the population in terms of gender and age distribution⁷.

Based on the respondents' views, three-quarters thought there should be a protection and preservation plan for groundwater, while about half felt responsible for contributing to it. More than 90% of survey participants are aware of the chemical industry in the area. However, only slightly above half of them are concerned, to a great or moderate extent, that there may be risks associated with this in terms of groundwater quality. Regarding the WTP, about one-third of survey participants stated that they are not willing to pay to support the expansion of the MAR scheme (Appendix, Fig. 2), with the current already high level of municipal/income taxes appearing to be the main reason for such a decision.

Following our expectations, the prevailing share of survey participants who indicated non-zero WTP were aware of problems with groundwater quantity and felt a responsibility to contribute to a groundwater protection plan, have high education and are full or part-time employees. Furthermore, their financial support followed the following distinct categories of the MAR scheme's benefits: on average 40% for the use of groundwater by future generations; 23% for groundwater-dependent ecosystems; 21% for the use of groundwater by the members of their household and 16% for the use of groundwater by other members of the local community. These results clearly support the importance of the MAR scheme's non-use benefits.

In addition, using parametric estimations, we investigated how a set of explanatory variables could explain whether a person is willing to pay to support the MAR scheme's expansion. The explanatory variables for our model – determinants of WTP - were partially selected following the study by Schinck et al. (2020). Using the Probit model (Eq. 3), we obtained the average partial effects with robust standard errors (Appendix, Table 2). The Probit model is a binary response model, allowing an estimation of the partial effect of any explanatory variable on the binary dependent variable (Wooldridge 2012).

$$P(y = 1|\mathbf{x}) = \Phi(\mathbf{x}\beta) \quad (3)$$

where $\Phi(\bullet)$: is the standard normal cumulative distribution function,
y: binary response variable,

\mathbf{x} explanatory variables.

Most estimated effects are statistically significant and consistent with the expected parameter's sign (Appendix, Table 2). More specifically, the probability that respondents will be willing to pay a non-zero amount increases when the respondent:

⁷ 56.5% percent of our respondents are female, corresponding share for Tarnow population in 2020 was 52.7%. Our sample is characterized by the following age distribution of respondents: 19.6% in age group 18–30 years, 43.5% in group 30–45 years, 37% aged 45+ years.

Table 3 Indicators used in the calculation of MAR scheme benefits based on WTP

Indicator	Unit of measurement	Value	95% confidence interval
Number of MAR system users	Number of inhabitants	40,000	
Annual population number growth rate	%	-0.23	
Mean monthly WTP	Euro	2.39	(1.88; 2.98)
Median monthly WTP	Euro	1.95	(1.24; 2.49)
Beneficiaries with zero WTP	%	35	

Source: Data provided by Tarnów Waterworks; own calculations based on survey results

- believes that there should be a protection and preservation plan for groundwater;
- is younger (base group for age variable is 18–30 years);
- has close to average or above-average income (base group for income variable is below average level);
- has higher education (base group for education variable is high school).

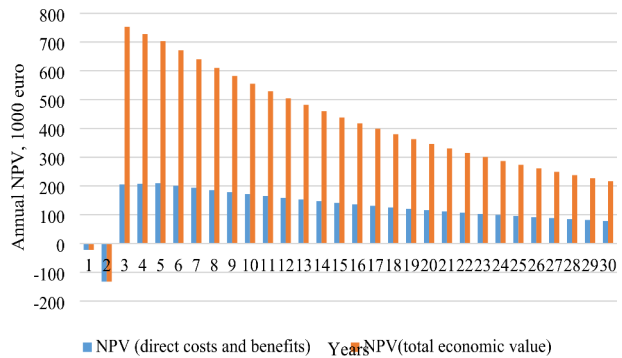
Another important finding for the MAR scheme expansion is that the prevailing share of respondents (82%) has no concerns about the safety of the drinking water supply from the MAR system.

3.2 Benefit Analysis

We estimated the mean and median WTP along with a 95% confidence interval using Krinsky and Robb's Procedure (Jeanty 2007). Mean and median WTP were obtained controlling for the respondent's characteristics: demographics, income level, education level, and green commitment. According to the literature, the mean value of WTP obtained, multiplied by the target population number serves as an annual estimate of benefits (Rupérez-Moreno et al. 2017). However, we have a noticeably skewed distribution of WTP (see Appendix, Fig. 2). Thus, the median is the preferred measure of central tendency, given that the median is more resistant to outliers than the mean. We calculated the annual estimate of benefits as a product of the number of MAR system users (accounting for the annual population growth rate for the study area) and the weighted median annual WTP amount weighting based on the shares of respondents who specified non-zero and zero WTPs (Table 3).

3.3 Feasibility of MAR Scheme Expansion

To check the economic feasibility of the MAR scheme's expansion, we first compared only direct costs and benefits associated with it. We applied a financial discount rate of 4% to obtain the discounted value of the direct benefits, the present value of future costs and initial capital costs over the 30-year project horizon. Since the operation phase of the expansion is expected to start in the 3rd year of the project, values for the first two years are negative, reflecting the capital costs (Fig. 3). The positive differences obtained between direct costs and benefits suggest that the MAR scheme's extension is economically feasible with an expected NPV over 30 years of €3.7 million. NPV is approaching around €12.1 million

Fig. 3 Annual net present value of the MAR scheme's expansion

when calculated as the difference between costs and the expected total economic value of the MAR scheme's extension.

3.4 Feasibility of the MAR Scheme Under Different Scenarios

It is essential to account for uncertainty in CBA studies. To incorporate this element in our analysis, we developed three scenarios with plausible variations of the main CBA parameters and checked how sensitive the net present value (NPV) of the MAR scheme's extension is to them. We developed the three scenarios (conservative, neutral and optimistic) based on the following parameters:

- range of capital costs associated with the MAR scheme's expansion;
- range of WTP median values (based on an estimated 95% confidence interval);
- variation of weights for the median value: 10% variation of the share of the targeted population with zero WTP.

We aimed to investigate the sensitivity of NPV to the changes as mentioned above in the parameters. Under all scenarios, NPV is positive, suggesting that it is profitable to implement the MAR scheme's expansion plan in any of the assumed conditions (Table 4).

3.5 Assessment of Socio-Economic Risks

Experts' assessment of socio-economic risks associated with the MAR scheme expansion is a complementary way to account for uncertainty in our CBA study. Economic risks along with health, environmental, technical and management risks can incur by implementing MAR schemes. Primary economic risks of MAR are related to the financing of MAR projects and benefits' realisation over time. One of the core discrepancies in the financing of water projects is that water users (primary stakeholders who benefit from them) often have insufficient financial sources to support these projects (Maliva 2014). Moreover, there is a time lag between construction costs and the realisation of benefits. Therefore, burdens associated with the financial constraints of MAR schemes' implementation may lead the primary beneficiaries to consider the investment in the MAR system infeasible in terms of costs and benefits. Thus, governmental support through subsidies is often considered to be justified in

Table 4 Assumptions on costs and benefits values and NPV under each considered scenario

Scenario	Assumptions		NPV over 30 years, thou. euro	Change compared to neutral scenario, %
	Costs	Benefits		
Conservative	The maximum value of capital costs	Including only direct benefits	3,724.1	-55
Neutral	The average value of capital costs	Lower bound of the confidence interval of estimated WTP median value; 45% of the targeted population has zero WTP	8,252.0	
Optimistic	The minimum value of capital costs	Estimated WTP median value; 35% of the targeted population has zero WTP (based on survey data)	12,117.3	47

such cases, though subsidies may sometimes create incentives that induce water-inefficient behaviour, e.g., non-sparing water use (Maliva 2014).

Contingent valuation techniques are commonly applied to reveal the WTP for MAR systems to record non-use values (existence, bequest and altruistic) of water use. However, they may sometimes struggle with several potential biases (Boardman et al. 1996) due to the hypothetical nature of respondents' answers, as their statement of WTP does not imply conversion into the actual payment obligation (Maliva 2014). Thus, there may be a high risk that the realisation of these potential biases (more severely in case of improper survey design) will result in an overestimation of potential benefits, which in turn will inflate NPV values and affect the decision regarding the economic feasibility of MAR. One of the approaches that has recently emerged to overcome these limitations of conventional stated preference techniques is deliberative monetary valuation (Christantoni and Damigos 2019), which might be one directions for future research in this study.

Failure to meet performance objectives is also considered a principal risk and source of uncertainty associated with MAR schemes (Maliva 2014; Rodríguez-Escales et al. 2018). Despite typical adverse results being mainly related to technical and health risks, they may also translate into economic ones (Imig et al. 2022). One example of such a transmission mechanism is when the problem of excessive well-clogging is remedied by pre-treating the water used for MAR with additional expenses. At the same time, the expectation that adequate pre-treatment would mitigate clogging is not always valid, as clogging during recovery may be a consequence of changes in water quality at the storage stage (Nandha et al. 2015). This significant operational risk can result in high maintenance costs and consequently lead to unforeseen expenses during the operation stage of the MAR scheme.

Finally, another source of economic risk might be that the revenues are lower than anticipated because of the not fully realised water demand. In addition, MAR systems can be sensitive to extreme climate events that are not easily foreseen; thus, it might be challenging to account for them at the planning stage. When it comes to drinking water demand, the percentage of MAR water in the total household water consumption during the dry season is strongly affected by the person's subjective perception of the risk of contracting a disease from drinking MAR water (Hasan et al. 2019).

For our case study, we considered several possible socio-economic risks, a comprehensive summary of which is provided in the review paper by Imig et al. (2022) (Appendix, Table 5). The local experts (Tarnów Waterworks staff) assessed the probability of occurrence for each risk. The approach of using experts' knowledge to investigate risk factors and assess the probability of risks for urban water supply options was applied by Ghandehari et al. (2020). However, the authors used the Fuzzy Delphi method to incorporate and interpret experts' opinions.

According to the experts' assessment, the risk for our case study, which is considered to have medium probability, is "lower benefits than anticipated due to overestimated WTP" since discrepancies between stated and actual WTP are quite probable. However, this risk can have minor consequences, since the NPV calculated accounting only for direct benefits is already positive. Among the other considered socio-economic risks, changing standards for end-users are expected by experts to have major consequences, while a moderate level of risk outcomes is forecast for lack of financial support and environmental fees policy. The realisation of other risks is expected to have minor consequences. There are no reasons to expect that demand for drinking water might not be fully realised, that is why this risk is not applicable to our case study.

4 Summary and Conclusions

Managed aquifer recharge (MAR) schemes play an important role among the techniques used to address water quantity and quality challenges. Along with assessing their technical and institutional feasibility, it is essential to ensure their economic feasibility and viability. Cost-benefit analysis (CBA) has been widely used for the economic evaluation of MAR and other water management projects (wastewater treatment, desalination, water-saving irrigation systems, etc.). CBA allows the inclusion of non-use values, revealed through contingent valuation methods, among benefits. This is particularly important for MAR schemes since they can support both use and non-use benefits associated with groundwater use. One of the challenges with applying this combined methodological approach (CBA and CV) is its data-intensiveness and the need to conduct a survey to record the opinions of the local stakeholders and civil society, which directly benefited from or was affected by the MAR scheme implementation.

In this paper, we performed a CBA for a potential MAR scheme expansion in Tarnów, southern Poland. This expansion is expected to increase the water withdrawal of the well field by approx. 30% with simultaneous control and improvement of groundwater quality. Our survey results suggest that the non-use benefits of the MAR scheme in the area can be significant for the local population. From a social perspective, the most essential non-use benefit appears to be the bequest value, while the MAR scheme's environmental benefit

is related to mitigating the adverse effects of a functioning chemical plant that may lead to contamination of drinking water in the case study area. The net present value (NPV) was calculated as the difference between the discounted total economic value of the MAR scheme (from both use and non-use values) and the associated costs. A positive NPV value was found, revealing that the MAR's expansion and operation can be economically feasible, even under the most pessimistic (conservative) of the three developed scenarios. Furthermore, the results obtained from the sensitivity analysis performed for these scenarios (conservative, neutral, optimistic) provide a reliable sign of the financial sustainability of the MAR scheme's extension, even under the changing social and economic circumstances.

This paper also outlines possible socio-economic risks associated with the MAR scheme in the study area and the expert assessment of their occurrence probability and possible consequences. Policy-makers should be aware of and consider these risks, especially the risks with a high likelihood and/or severe consequences. Based on the assessment of local experts for our study area, among the considered risks, changing standards for the end-users could be the only one with major consequences expected in case of its realisation.

To the best of our knowledge, this study is the first to assess the MAR scheme's economic feasibility in Poland. The example of the MAR scheme economic assessment provided in this paper might be useful from the methodological point of view for similar research in other larger towns located in the Dunajec river catchment areas, such as Nowy Targ or Nowy Sącz (Fig. 1). In these two areas, the IBF and infiltration ditches, the two MAR methods analysed in this paper, have been proven to be potentially suitable for implementation from the technical point of view, based on the general suitability maps for MAR published on The Global Groundwater Information System of IGRAC and performed in the DEEP-WATER-CE project. They might help to increase the safety of drinking water supply in these regions in the future, which is particularly important in terms of adaptation to climate change, which harms groundwater resources. Thus, the economic approach applied in this paper can also be used there to validate its economic feasibility.

The methodology applied in this paper combines a cost-benefit analysis, contingent valuation study, sensitivity analysis and expert assessment of socio-economic risks. Thus, this paper can also contribute to the existing literature as a good practical example providing the base for comprehensive economic assessment of future sustainable water management projects, including MAR schemes. These water management projects aim to reach goals, for example, that of the European Green Deal, by 2030 and to facilitate the achievement of sustainable development goals, such as SDG 6, which promotes clean and affordable water for all (United Nations 2018). In addition, this study could be further extended using multiple periods and observing the behaviour of water users and the changes in their WTP throughout the duration of the water project. Another potential direction for future research is the application of the Fuzzy Delphi methodology to assess risks associated with the MAR scheme using expert opinions.

5 Appendix

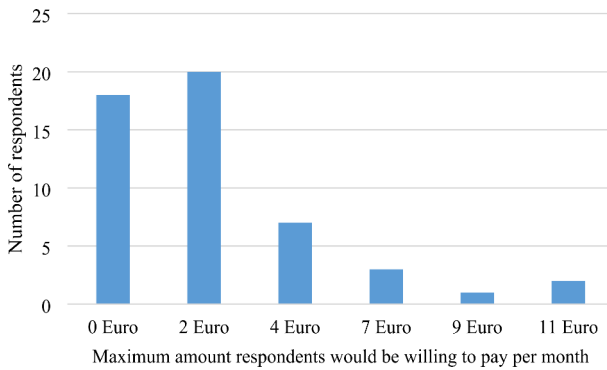


Fig. 2 WTP of the local population for the MAR scheme's expansion

Table 2 Effect of respondent's characteristics on WTP probability: Binary Probit model results

Variable	Definition	Average partial effect (Robust standard error)
Gender	Male	-0.213*** (0.091)
Age	30–45	-0.338*** (0.049)
	45+	-0.453*** (0.091)
Income	Close to the average level	0.278** (0.113)
	Above the average level	0.315*** (0.096)
Education	Bachelor degree	-0.412*** (0.125)
	Master degree and higher	0.324** (0.132)
Protection plan	Should be in place	0.738*** (0.195)
Concern chemical contamination	Great or moderate concern	0.189 (0.127)
Household impact	Household impacts groundwater quality	-0.491*** (0.13)
Number of observations	42	
Wald χ^2	360.09	
Pseudo R^2	0.499	

*** correspond to p -level < 0.01

Table 5 Matrix of socio-economic risks for MAR extension

Socio-economic risk	Not applicable	Risk probability			Risk consequences		
		Low	Medium	High	Low	Medium	High
Lack of funding/financial support		+				+	
Unplanned additional costs (installation, maintenance etc.)		+			+		
Changing standards for end-users		+					+

Table 5 Matrix of socio-economic risks for MAR extension

Socio-economic risk	Not applicable	Risk probability			Risk consequences		
		Low	Medium	High	Low	Medium	High
Insufficient communication and negative risk perception by the general public		+			+		
Lack of acceptance and trust by the general public		+			+		
Water demand not fully realised	+						
Lower benefits than anticipated due to overestimated WTP			+		+		
Other: Environmental fees policy (including local) - economic and legal aspects		+				+	

Author Contribution **O. Halytsia**: conceptualisation, methodology, data processing, performing calculations and estimations, writing-original draft; **M. Vracholi**: conceptualisation, design, methodology, writing-review, and editing; **K. Janik**: investigation, visualisation, data collection, review, and editing; **S. Sitek**: investigation, data collection, review, and editing; **G. Wojtal**: material preparation, data collection, and review; **A. Imig**: conceptualisation, design, writing-review, and editing; **A. Rein**: conceptualisation, design, writing-review, and editing; **J. Sauer**: conceptualisation, methodology, review, and editing.

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Data Availability Data and material will be made available on reasonable request to the authors.

Declarations

Ethical Approval Not applicable.

Consent to Participate Not applicable.

Consent to Publish All authors approved the submission and consented to publication.

Competing Interests The authors declare that they have no known competing financial interests or personal relationships that could have appeared to influence the work reported in this paper.

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