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# Analysing economic factors and forest cover impacts on water resource management: A comparative study of seven Slovak reservoirs

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**Abstract:** Water reservoirs (WR), as a key source of drinking water in Slovakia, face increasing challenges due to environmental pressures, economic aspects and technological limitations related to water collection and treatment. The aim of the study was to analyse and compare the economic external factors of seven major Slovak drinking water reservoirs (Málinec, Tručec, Nová Bystrica, Hriňová, Klenovec, Starina, and Bukovec). The results of the study evaluated the following economic factors: (*i*) drinking water supply, (*ii*) drinking water demand, and (*iii*) average annual costs for drinking water treatment and purification. The last-mentioned was studied in more detail to investigate how the catchment's forest cover affects annual water treatment costs. The analysis of economic factors showed that smaller reservoirs with a lower technical base, such as Hriňová and Turček, are more sensitive to seasonal and ecological fluctuations, leading to greater cost variability and more negative management effects. In contrast, large reservoirs such as Starina and Nová Bystrica exhibit greater stability and resilience to these impacts, and economic factors positively influence water resources management. The study also demonstrates that the catchment's forest cover and reservoir volume significantly contribute to lower drinking water treatment costs in Slovakia. These findings highlight the economic relevance of forested catchments for drinking water supply and underline the importance of integrating forest management considerations into water resource management.

**Keywords:** drinking water treatment costs; forest ecosystem services; Slovakia; water reservoirs

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Water is one of the natural resources that is essential for the maintenance of our planet and life on it. It is expected that the growing world population and increasing human wealth will lead to greater withdrawal of drinking water, underscoring the importance of water resource management. The current annual potential of water resources in Europe is approximately 7 418 $km^3$, with an average per capita share of 9 300 $m^3$ (Musie, Gonfa 2023). However, the potential of water resources does not express the current water consumption, but rather indicates how much water is available for personal and industrial consumption in the case of its treatment. This depends on various factors such as the quality of available resources, the forest cover of the catchment area, environmental pollution, land use patterns or the method of water withdrawal from different surface and groundwater sources (Giri, Qiu 2016). Although water quality is declining globally, the opposite trend has been observed in Europe (WHO/UNICEF Joint Monitoring Programme 2022). This is mainly due to strict environmental legislation in this area (Trenčiansky et al. 2025). The implementation of such policies and approaches, which are aimed at maintaining good water status, then reduces the costs of water treatment and purification (Giri, Qiu 2016).

The Slovak Republic is characterised by a wealth of water resources, which are key to ensuring the supply of drinking water to the population. In Slovakia, 82.2% of drinking water comes from groundwater and 17.8% from surface water (Mederly et al. 2019). The average water consumption per capita is approximately 30 000 litres per year (VÚVH 2023). The largest volume of surface drinking water comes from reservoirs (e.g. Starina, Nová Bystrica) and is used mainly in areas with limited underground springs (e.g. central and eastern Slovakia). The Slovak drinking water supply system consists of 14 water companies, with prices set through decisions of the Regulatory Authority for Network Industries (Kapalo 2023). Although the price is regulated, it is also based on technological and chemical requirements for water treatment (Trenčiansky et al. 2025).

It follows that in addition to environmental and technological problems of water management, it is important to address economic ones, such as the potential of water resources (i.e. drinking water supply), total consumption (i.e. drinking water demand) and their final price. The water price in Europe ranges from the highest in Denmark (up to 10 $EUR \cdot m^{-3}$) to the lowest in the United Kingdom (up to 2.5 $EUR \cdot m^{-3}$) (Smart 2021). The average unit price for water and sewage combined, excluding value-added tax, in Slovakia in 2022 was 2.57 $EUR \cdot m^{-3}$, which is comparable to the price of water in the V4 countries (Hogenová 2025). The average price for water in Poland, Hungary and the Czech Republic oscillates around 3 $EUR \cdot m^{-3}$ as well (Hogenová 2025; Statista Research Department 2026; Vítková et al. 2022).

However, the final cost of water treatment is influenced by many factors, with forest cover in the catchment considered one of the key factors with a positive and significant impact on water treatment cost savings (Horváthová 2022; Warziniack et al. 2017; Lopes et al. 2019). Moreover, the highest quality water sources, characterised by a higher ecological status, are typically associated with densely forested areas (Neary et al. 2009), as the quality of surface drinking water sources has been found to be higher in areas with higher forest cover (Ellison et al. 2012; Brogna et al. 2017a, b; Lopes et al. 2019). This is due to the complex interactions between forests and water, which have been described in many global studies (Neary et al. 2009; François et al. 2024).

Therefore, the aim of the paper is to fill the identified gap in Slovak research, analyse selected economic factors influencing the management of water reservoirs, and examine the relationship between the forest cover of the catchment and the costs of drinking water treatment in Slovakia.

## METHODS

The studied reservoirs represent the surface drinking water abstraction sector across Slovakia, excluding small surface sources. The study was divided into three phases. Firstly, we calculated the average water treatment costs, the maximum and minimum values in the analysed time series, and the rate of cost variability, expressed as the standard deviation. The calculation was based on data provided by water companies for the years 2010–2022. Secondly, we analysed the economic factors (drinking water demand, supply, water treatment costs) for individual water reservoirs using data from available reports and personal interviews with representatives of WR. Thirdly,

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we analysed the dependence of water treatment costs on forest cover and total volume in the selected reservoir catchments using MS Excel and Statistica (Version 14.0.0.15, 2020) software. These relationships were investigated through elaboration of the two original scientific hypotheses:

$H_1$: Higher forest cover in the reservoir catchment is associated with lower unit costs of drinking water treatment, due to protective and filtering functions of forests.

$H_2$: Larger reservoir volume is associated with lower unit costs of drinking water treatment, due to improved sedimentation capacity.

**Study locations (water reservoirs).** There are over 230 small and over 40 large water reservoirs in Slovakia, but they serve multiple purposes, not just water supply. Only eight key water reservoirs are solely for water supply: WR Hriňová, WR Málinec, WR Klenovec, WR Rozgrund, WR Nová Bystrica and WR Bukovec (Slovak Water Management Company 2019). The research was carried out in seven water reservoirs in Slovakia, of which five are considered significant in water supply (Figure 1, Table 1).

**Economic factors influencing the management of water reservoirs and drinking water in Slovakia.** Decision-making in strategic management must be based on a thorough assessment of the internal and/or external environment to identify the factors that affect the managed unit. Subsequently, it is important to classify these factors as having positive, neutral, or negative effects. The results of the analysis of relevant factors directly influence the selection of the most appropriate management alternative (Srdjevic et al. 2012). We analysed the selected economic factors (Table 2) of seven water reservoirs that manage the dominant share of surface drinking water resources in Slovakia. The analysis was based on a pilot study of PESTLE (political, economic, social, technical, legal and environmental) factors affecting the management of the selected water reservoirs (Trenčiansky et al. 2025).

We obtained information about economic factors influencing the management of water reservoirs from personal interviews with representatives of the water reservoirs and from internal documents (including drinking water price lists, numbers of drinking water consumers, and water treatment costs).

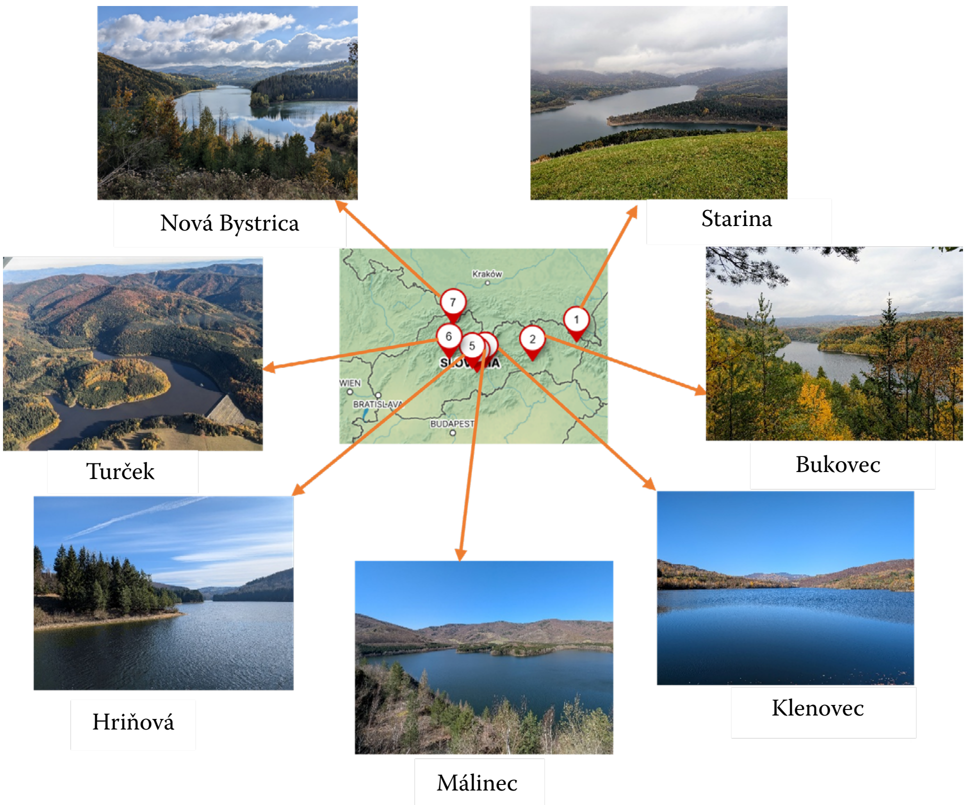


Figure 1. Study locations

Photo: Marek Trenčiansky

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Table 1. Parameters of the analysed water reservoirs (WRs)

| Water reservoir | | Málinec | Turček | Nová Bystrica | Hriňová | Klenovec | Starina | Bukovec |
|---|---|---|---|---|---|---|---|---|
| Year | | 1994 | 1999 | 1989 | 1965 | 1974 | 1988 | 1976 |
| Basin | | Ipeľ | Váh | Kysuca | Hron | Slaná | Bodrog | Bodva |
| Sub-basin | | Ipeľ | Turiec | Riečnica | Slatina | Rimava | Cirocha | Ida |
| Coordinates | | 48°31'17"N 19°39'50"E | 48°45'48"N 18°56'19"E | 49°20'29"N 19°02'33"E | 48°36'02"N 19°32'26"E | 48°36'28"N 19°52'32"E | 49°02'40"N 22°15'28"E | 48°43'04"N 21°07'37"E |
| Altitude | m a.s.l. | 345 | 777 | 599 | 565 | 377 | 340 | 416 |
| WR volume | mil. $m^3$ | 26.7 | 10.6 | 32.8 | 7.38 | 8.43 | 59.8 | 23.4 |
| WR water area | $km^2$ | 1.38 | 0.54 | 1.81 | 0.56 | 0.71 | 3.11 | 1.28 |
| Dam height | m | 48 | 59 | 57 | 42 | 33 | 50 | 24 |
| Consumers | ths. | 63 | 89 | 170 | 95 | 50 | 375 | 225 |
| Treatment | $L \cdot s^{-1}$ | 280 | 120 | 700 | 125 | 85 | 1 000 | 350 |

Source: Slovak Water Management Company, s.p.; Central Slovak Water Supply Company, a.s.; Eastern Slovak Water Supply Company, a.s.; Northern Slovak Waterworks and Sewage Works, a.s.

**The analysis of factors which influence the costs of drinking water treatment.** Following a comprehensive evaluation of management factors across all seven reservoirs, hypothesis testing was restricted to a subset of four sites. Excluding the remaining three reservoirs was necessary to maintain analytical objectivity, as their observed variances appeared to be driven by stochastic factors unrelated to reservoir scale or forest cover density. The three WRs were excluded from the research, as the following specific conditions occurred in them (Trenčiansky et al. 2025):

(*i*) WR Turček – the costs of drinking water treatment are significantly increased, as the occurrence of the cyanobacterium *Planktothrix rubescens* has been recorded in recent years.

(*ii*) WR Hriňová is the oldest water reservoir with the oldest water treatment plant using outdated technologies, which leads to increased costs for water treatment.

(*iii*) WR Bukovec has increased costs for drinking water treatment due to the elimination of antimony and arsenic, which originate from the geological subsoil of the catchment.

The data on the costs of drinking water treatment were sourced from the accounting documents of water companies for the consumption of chemicals used in drinking water treatment (hydrochloric acid, lime hydrant, sulphates, starch, etc.) in the given water reservoir during the year under study. The cost of chemical purchase, i.e. the consumption of chemicals for water treatment, constitutes the highest component of operating costs for water treatment. The formulation of hypotheses $H_1$ and $H_2$ reflects the limited number of surface-water reservoirs available for analysis in Slovakia. Rather than aiming at broad statistical generalisation, the hypotheses are designed to test whether theoretically well-established variables – namely the forest cover and reservoir volume impact drinking water

Table 2. Analysed economic factors and their description

| Factor | Criteria | Impact |
|---|---|---|
| Supply (water tank volume – compared to all surveyed WRs) | low < 10/moderate 10–25/high > 25* | P/Nt/Ng |
| Demand (share of annually treated water to the volume of the water reservoir – compared to all studied WRs) | low < 20/moderate 20–30/high > 30* | P/Nt/Ng |
| Price (cost of water treatment in the period 2010–2022 compared to all studied reservoirs; cost of purchasing chemicals used for raw water treatment) | low < 10/moderate 10–15/high > 15* | P/Nt/Ng |

*The limits for low/medium/high were determined based on mutual comparison of the reservoirs; WR – water reservoir; P – positive; Nt – neutral; Ng – negative

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treatment costs – can be empirically observed under Slovak conditions in four chosen WRs (Málinec, Klenovec, Nová Bystrica, Starina). Given the case-based nature of the dataset, the hypotheses are examined using regression analysis as an exploratory tool, focusing on the direction and consistency of relationships rather than on precise parameter estimation. The dependent variable in the regression equation is water treatment costs; the independent variables are the forest cover of the WR catchment and the reservoir volume. The results should therefore be interpreted as evidence supporting or rejecting the proposed mechanisms in the analysed reservoirs, rather than as universally applicable causal effects.

## RESULTS

The results of case studies of seven water reservoirs (Málinec, Turček, Nová Bystrica, Hriňová, Klenovec, Starina, and Bukovec) indicate the complexity of the economic factors influencing the management of drinking water treatment in Slovakia. Each of the analysed reservoirs is located in a different geographical, ecological, and socio-political context, as reflected in the diversity of challenges faced by water utilities in relation to the economic factors that affect them (Table 3). At the same time, the study covers all types of managed WRs in Slovakia. Economic factors significantly affect the efficiency and sustainability of drinking water treatment management and are evident in differences in water treatment costs across reservoirs (Table 4).

In terms of drinking water supply, measured by the volume of the water reservoir (supply = maximum potential for drinking water supply), the largest reservoirs are Starina, Nová Bystrica, and Málinec. These have the highest potential for drinking water supply, so the effect of the supply factor is assessed as positive. On the other hand, the smallest reservoirs are Hriňová and Turček, where the small reservoir volumes negatively affect their management, as the water treatment plant must be technologically secured and equipped regardless of the reservoir's size or the volume of water withdrawn. The average water withdrawal from the studied reservoirs ranges from 2.6 million $m^3 \cdot year^{-1}$ in the Málinec reservoir to 15.05 million $m^3 \cdot year^{-1}$ in the Starina reservoir. This indicates that the potential of water reservoirs currently exceeds drinking water withdrawals, suggest-

Table 3. Input data for the economic analysis of water reservoirs (WRs) in Slovakia

| Water reservoir | Unit | Málinec | Turček | Nová Bystrica | Hriňová | Klenovec | Starina | Bukovec |
|---|---|---|---|---|---|---|---|---|
| Average water extraction | mil. $m^3 \cdot year^{-1}$ | 2.60 | 3.64 | 7.05 | 3.93 | 2.37 | 15.05 | 4.02 |
| Catchment area | $km^2$ | 83.13 | 29.32 | 29.02 | 72.41 | 88.82 | 125.40 | 55.37 |
| Forest area of the catchment | $km^2$ | 47.77 | 28.48 | 43.15 | 62.94 | 57.35 | 103.88 | 45.21 |
| Catchment forest cover | % | 57.47 | 97.13 | 73.12 | 86.92 | 64.57 | 82.84 | 81.65 |
| Proportion of coniferous trees | % | 55 | 68 | 88 | 54 | 24 | 8 | 17 |
| Proportion of broadleaved trees | % | 45 | 32 | 12 | 46 | 76 | 92 | 83 |
| Average age of forest stands | year | 46 | 58 | 49 | 48 | 46 | 46 | 67 |
| Average growing stock | $m^3 \cdot ha^{-1}$ | 245 | 320 | 272 | 221 | 214 | 157 | 259 |
| Average costs for drinking water treatment ('costs') | EUR ths. $m^{-3} \cdot year^{-1}$ | 11.79 | 14.98 | 8.73 | 19.43 | 13.48 | 3.40 | 21.80 |
| Maximal costs | EUR ths. $m^{-3} \cdot year^{-1}$ | 13.56 | 23.69 | 12.62 | 24.80 | 19.43 | 4.65 | 27.92 |
| Minimal costs | EUR ths. $m^{-3} \cdot year^{-1}$ | 7.80 | 7.61 | 5.26 | 8.88 | 10.43 | 2.44 | 16.76 |
| Standard deviation of the costs | – | 1.38 | 6.04 | 2.13 | 4.58 | 2.42 | 0.63 | 3.12 |
| Water withdrawal/tank volume ratio | % | 9.7 | 34.3 | 21.5 | 53.3 | 28.1 | 25.2 | 17.2 |

Source: Forest management information system of the National Forest Centre of the Slovak Republic – ISLPH (forest cover); costs – own calculation

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Table 4. Economic factor assessment

| Factor | Málinec | | Turček | | Nová Bystrica | | Hriňová | | Klenovec | | Starina | | Bukovec | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | criteria | effect | criteria | effect | criteria | effect | criteria | effect | criteria | effect | criteria | effect | criteria | effect |
| Suply | high | P | moderate | Nt | high | P | low | Ng | low | Ng | high | P | moderate | Nt |
| Demand | low | P | moderate | Nt | moderate | Nt | high | Ng | moderate | Nt | moderate | Nt | low | P |
| Drinking water treatment costs | moderate | Nt | high | Ng | low | P | high | Ng | moderate | Nt | low | P | high | Ng |

P – positive; Nt – neutral; Ng – negative

ing a stable long-term supply for Slovak households. The average demand for drinking water, measured by the ratio of water withdrawal to reservoir volume, is assessed as low to medium, indicating a positive to neutral effect on the management of water reservoirs and water resources. The highest demand is at the Hriňová reservoir, accounting for 27% of its total volume, which we consider a positive effect for water resources management.

The average costs of water treatment in the years 2010–2022 ranged from EUR 8.73 per 1 000 $m^3$ (Nová Bystrica) to EUR 21.80 per 1 000 $m^3$ (Bukovec), which is mainly related to the technological level of the treatment plant, the size of the reservoir, the ratio of pumped water to the total volume and the environmental state of the catchment. The water treatment costs in the Bukovec reservoir are affected by the presence of antimony and arsenic in the catchment's geological subsoil, which requires additional purification of water resources using sulphates. Smaller reservoirs with lower technical sophistication are more sensitive to seasonal and ecological fluctuations, leading to greater cost variability. This concerns the Hriňová waterworks (EUR 19.43 per 1 000 $m^3$), which uses outdated technology with repeated failures, and the Turček waterworks (EUR 14.98 per 1 000 $m^3$), which has problems with cyanobacteria *Planktothrix rubescens*. On the contrary, large reservoirs such as Nová Bystrica or Starina show higher stability and resistance to these influences. The assessment of this criterion shows the diverse effects of the given factor on the management of water resources, with low-cost values expressing a positive effect (Nová Bystrica, Starina) and, conversely, high negative ones (Turček, Hriňová, Bukovec). Two of the analysed reservoirs have medium costs for drinking water treatment, which has a neutral effect on their management (Klenovec, Málinec). The statistical analysis of potential factors influencing the average costs of drinking water treatment (forest cover of the catchment, volume of the water reservoir, depth of the water reservoir, area of the catchment, amount of drinking water withdrawn), identified two factors as statistically significant: forest cover of the catchment and volume of the water reservoir (Figures 2 and 3).

Regression models, as well as estimated parameters, are statistically significant at the $\alpha = 0.05$ level. With increasing forest cover in the catchment, the average costs of water treatment decrease, confirm-

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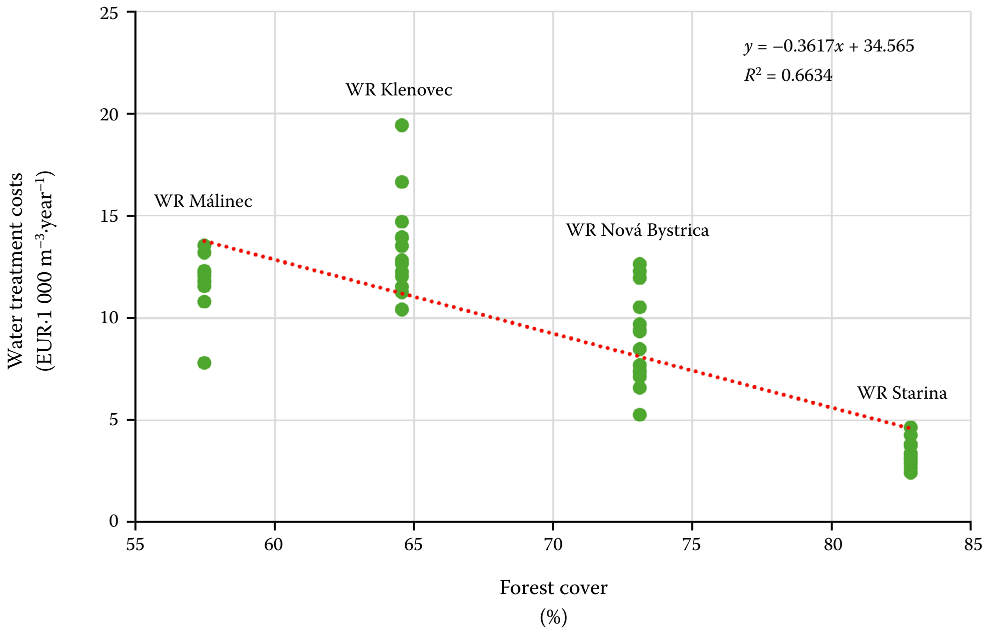


Figure 2. Dependence of average water treatment costs on the forest cover of the water reservoir (WR)'s catchment

ing our hypothesis $H_1$. In the given catchments, the forest acts as a natural filter, regulates erosion, and stabilises the chemistry of runoff, thereby improving water quality. Similarly, as reservoir volume increases, the cost of drinking water treatment decreases. With a larger reservoir volume, natural sedimentation is better utilised, and a larger volume of water is more resistant to the impacts of pollution (e.g. torrential rains). The negative correlation between forest cover in the catchment and water treatment costs confirms the importance of forest ecosystem services for water protection. Forest ecosystems within given catchments reduce the need for intensive technological water treatment by retaining sediment and filtering nutrients. At the same time, it has been shown that the accumulation volume of selected WRs plays a key role in stabilising raw water quality, as a longer

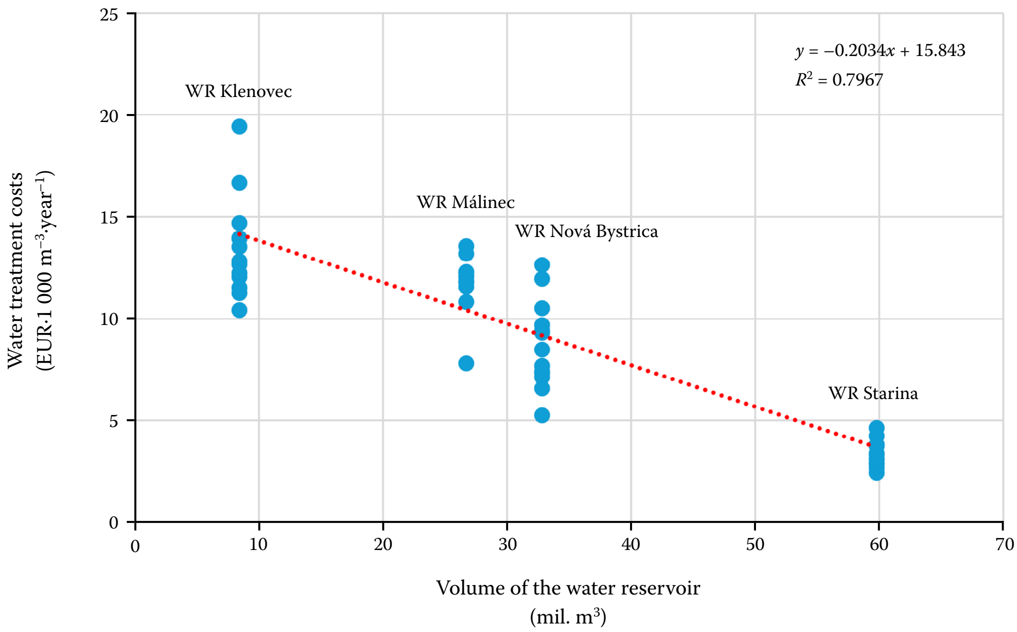


Figure 3. Dependence of average water treatment costs on the volume of the water reservoirs (WRs)

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retention time supports natural sedimentation, thereby directly reducing the costs of coagulation and filtration in the treatment plant. Using statistical analysis of two independent factors confirmed our hypothesis $H_2$ in four analysed WRs: the forest cover of the catchments and reservoir volume have a positive effect on the costs of drinking water treatment.

## DISCUSSION

As the results show, the increasing demand for drinking water in Slovakia (Illes et al. 2025) will be met by surface water sources, given that, on average, only a third of the drinking water from the studied reservoirs is pumped and treated. This fact reflects the European trend, which shows that the average water consumption of Europeans is lower than the potential of European water resources (Musie, Gonfa 2023). The analysis of drinking water treatment costs showed that reservoir volume and catchment location significantly affect treatment costs. The lowest water treatment costs were observed for the reservoir with the largest volume, while the highest costs were calculated for the smallest reservoirs, which also face environmental problems, such as the occurrence of cyanobacteria or hazardous substances in the catchment's subsoil. This confirms the finding that the quality of raw, respectively untreated water, affects the final price of drinking water (WHO 2008; Wang 2016), which should motivate water companies operating reservoirs to improve the quality of water resources in the catchment in the long term (Danelon et al. 2021).

Given that the analysed reservoirs are characterised by a high level of forest cover, which is at least 50%, companies should cooperate mainly with forest owners in the catchments, as it has been demonstrated that high forest cover in the catchment has a direct positive impact on the physical and chemical properties of water and reduces the need for intensive treatment (Ernst et al. 2004; Trenčiansky et al. 2022).

This is evident in the costs for drinking water treatment. Our results confirm the existence of increasing returns to scale in the drinking water treatment process. This phenomenon is present at two levels: technical and environmental. Technical returns to scale are linked to reservoir volume: higher storage capacity enables more efficient sedimentation and a more even distribution of fixed costs. This follows the argument that increasing returns in water management arise from larger supply sources, which have lower unit costs for water treatment and greater stability (Garcia, Thomas 2001). Environmental returns to scale are manifested through the catchment's forest cover, where extensive forest ecosystems synergistically filter pollutants, thereby reducing variable costs associated with the chemical treatment of raw water. It has been proven that higher forest cover in a watershed is generally associated with protecting water resources from contamination (Willis 2002; Abildtrup, Strange 2000; Ernst et al. 2004), reducing the amount of sediment, nutrients and contaminants (Robinson, Cosandey 2011; Amatya et al. 2003) and maintaining good water quality (Aust et al. 2011).

Future research should consider other forest-related factors that affect water quality, quantity, and the costs of drinking water treatment. Moreover, in Slovakia, it has not been studied in detail how/whether tree composition, slope, or stand age affects water management in general.

## CONCLUSION

This study has shown that the management of water reservoirs in Slovakia is significantly influenced by external economic factors, such as the supply and demand for drinking water, and the costs of drinking water treatment. These depend on reservoir size, catchment area, and the level of technology employed for water abstraction and treatment. Reservoir management is the responsibility of water companies, which must apply economic principles in their decision-making. The number of consumers is also a key factor in the system's sustainability: a larger number of consumers reduces unit costs and improves the return on investment. The age and volume of the reservoir also play significant roles in water treatment costs: in small reservoirs, the same demanding technology must be available as in large ones, whereas the return on investment for repairs and the water treatment technologies used is lower. In the long term, investments in modern technologies, as well as in the protection and restoration of water catchments, are therefore a decisive prerequisite for the economically sustainable operation of water reservoirs. The results also support hypotheses $H_1$ and $H_2$ within the analysed case-study framework, con-

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firming the relevance of forest cover and reservoir volume as key explanatory factors of drinking water treatment costs.

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