Factors affecting the cost of drinking water production

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ABSTRACT

The article summarizes the findings of a statistical analysis of the cost of drinking water production in the Czech Republic in 2018. Understanding the factors that influence the cost of drinking water production is important for choosing a cost-effective public drinking water supply system. We present the first study analysing the factors affecting the cost of drinking water production in the Czech Republic. We tested the following factors for their influence on the production costs of drinking water: the quantity of drinking water produced, the type of raw water (surface vs. groundwater), electricity consumption, and the treatment technologies and chemicals applied. The results suggested that drinking water production from groundwater was cheaper than from surface water. At the same time, some water treatment technologies and usage of some treatment technologies and chemicals increase production costs. The use of sodium hypochlorite, chlorine and demanganisation have the greatest impact on production costs. We have also confirmed economies of scale in the production of drinking water.

INTRODUCTION

The cost of drinking water treatment depends on the quality of raw water, treatment technologies, legal regulations, used energy sources, and the amount of treated water [1]. Regarding technological processes for water treatment, the use of gravity filtration and chlorine application has the greatest impact on costs. The cost of drinking water production is also influenced by the distance over which the water is distributed from the producer to the customer, and the method of this transport [1].

One of the most important factors affecting the cost of drinking water production is the quality of raw water. Numerous studies have found that improving source water quality reduces its treatment costs [2]. Due to greater natural purification, groundwater is usually considered cleaner than surface water [3], and the cost of treating it is lower than that of surface water [4].

Natural water purification is one of the most frequently mentioned benefits that nature provides to people, so-called ecosystem services [5]. Although the demand for valuing water-related ecosystem services is growing [6], research in this area is still scarce [7]. Valuation of the ecosystem service of groundwater purification has so far only been carried out in the Netherlands, using the replacement cost method [4]. Using this method, the value of groundwater purification can be calculated as the difference between surface and groundwater treatment costs. To use this method, it is therefore necessary to know how the costs of producing drinking water from surface water and groundwater sources differ. However, this issue has not yet been investigated in the Czech Republic.

Previous research into factors affecting drinking water production costs has focused primarily on North America and Western Europe. Therefore, we focused on Central Europe and analysed the costs of drinking water production in the Czech Republic. According to our information, this is the first study to examine parameters affecting the costs of drinking water production in Central Europe.

DATA

The data was obtained by combining the data that owners and operators of water supply and sewerage systems must report annually to the relevant water authorities (selected data from property records and selected data from operational records of water supply and sewerage systems, so-called VÚME and VÚPE data). This data was supplemented with other data, e.g. rates of charges for water abstraction. We performed the analysis on data for 2018.

We excluded observations from the database which had too low water production as well as those with too low or too high unit production costs. We assumed that these observations were entered incorrectly. We also excluded three abstraction points where more than 50 % of water production was technological water. In addition, we also excluded locations where infiltration is used. After cleaning the data, 3,253 observations remained (the total number of observations before cleaning was 3,566).

METHODOLOGY

In the short term, the costs of companies using environmental inputs are determined by the volume of production, company characteristics, costs of non-environmental inputs, costs of fixed factors, and characteristics of the natural capital used (non-environmental input) [5, 8].

Since we were not interested in the effects on total costs but on unit production costs, we used the following function based on previous research:

$$JNBP = \alpha + \beta 1 \ln VV + \beta 2\, EL + \beta 3\, PDV\_d + b1\, TECH1 + b2\, TECH2 + \ldots$$
$$\ldots + b30\, TECH30 + e \qquad (1)$$

where *JNBP* are unit production costs without water abstraction charges
VV is amount of water produced

Tab. 1. Descriptive statistics

Variable	Description	Number of observations	Average	Standard deviation	Min.	Max.
JNBP	Unit production costs without raw water abstraction charges (CZK/m^3)	3 253	12.73	9.77	0.52	49.9
VV	Amount of drinking water produced (km3/year)	3 253	176.1	1.82	0.02	87.16
EL	Unit consumption of electrical energy (kWh/m3 of drinking water produced)	3 253	0.71	1.36	0	43.64
PDV_d	Binary variable = 1 if the proportion of groundwater was >= 0.5 in the total water production at a given abstraction point	3 253	0.96	0.2	0	1
NoSludgeTreat	Binary variable = 1 if no sludge treatment was used	3 253	0.36	0.48	0	1
NoTreatment	Binary variable = 1 if according to VÚME, there was no water treatment technology category	3 253	0.55	0.5	0	1
Deacidification	Binary variable = 1 if deacidification by filtration, aeration was used	3 253	0.1	0.3	0	1
Demanganisation	Binary variable = 1 if demanganisation was used	3 253	0.11	0.31	0	1
Filtration	Binary variable = 1 if filtration was used	3 253	0.17	0.37	0	1
ChemDisinfection	Binary variable = 1 if chemical disinfection was used	3 253	0.38	0.49	0	1
Chlorine	Binary variable = 1 if chlorine was used	3 253	0.11	0.31	0	1
IronRemoval	Binary variable = 1 if iron removal was used	3 253	0.12	0.32	0	1
OtherAggregation	Binary variable = 1 if other aggregation agent according to VÚME was used	3 253	0.08	0.26	0	1
OtherTechnology	Binary variable = 1 if other technology according to VÚME was used	3 253	0.07	0.26	0	1
PotassiumPermanganate	Binary variable = 1 if potassium permanganate was used	3 253	0.06	0.24	0	1
RadonRemoval	Binary variable = 1 if radon was removed	3 253	0.08	0.27	0	1
SodiumHypochlorite	Binary variable = 1 if sodium hypochlorite was used	3 253	0.87	0.33	0	1

EL	*unit consumption of electrical energy (kWh/m^3 of water produced)*
PDV_d	binary variable characterizing the type of raw water
proměnné TECH 1–30	are binary variables characterizing the technologies and chemicals used in water treatment
a	is constant
β1–β3, b1–b30	are regression coefficients
e	is an error term

Since there is often a non-linear relationship between costs and the amount of produced water [1], we used natural logarithm of production volume (ln VV). The PDV_d variable was equal to 1 if the proportion of groundwater in the total water production at a given abstraction point was equal to or greater than 50 %. We had information on 17 technologies and 13 chemicals used in water treatment. However, some of these technologies and chemicals are not used very often, or their use is not frequent according to the VÚME database for the analysed year (2018). For the statistical analysis, we used only the following 13 technologies and chemicals with 5 % or more use in the year under review:

- deacidification,
- demanganisation,
- filtration,
- chemical disinfection,
- chlorine application,
- iron removal,
- without sludge treatment,
- without treatment (category according to VÚME database: without treatment, 1-stage and 2-stage treatment and infiltration)
- other aggregating agent,
- other technologies,
- potassium permanganate,
- radon removal,
- sodium hypochlorite.

Descriptive statistics for all variables are presented in *Tab. 1*

Since the costs of water production include charges paid for raw water abstraction, we first calculated the unit costs without charges. We calculated the unit costs without charges for an abstraction point a (JNBPa) as follows:

$$JNBPa = \frac{(CNa - PVVa * SPVa - PDVa * SPD)}{VVa} \qquad (2)$$

where	*CNa*	are total production costs at the abstraction point *a*
	PVVa	is amount of surface water abstracted at the point *a*
	SPVa	rate of charges for the abstraction of surface water at the point *a*

Tab. 2. Regression results. Dependent variable: JNBP (unit costs without charges)

	1	**2**	**3**	**4**	**5**	**6**	**7**	**8**	**9**
lnVV	-1.15***	-1.14***	-1.15***	-1.14***	-1.14***	-1.14***	-1.14***	-1.13***	-1.12***
	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)	(-0.11)
PDV_d	-2.06**	-2.09**	-2.13**	-2.15**	-2.32***	-2.37***	-2.47***	-2.45***	-2.24**
	(-0.95)	(-0.94)	(-0.94)	(-0.93)	(-0.90)	-0.90)	(-0.89)	(-0.89)	(-0.88)
EL	0.49**	0.49**	0.49**	0.49**	0.49**	0.49**	0.49**	0.50**	0.52**
	(-0.23)	(-0.23)	(-0.23)	(-0.23)	(-0.23)	(-0.23)	(-0.23)	(-0.24)	(-0.24)
Deacidification	-0.74	-0.711	-0.73	-0.75	-0.73	-0.74			
	(-0.64)	(-0.63)	(-0.62)	(-0.62)	(-0.62)	(-0.62)			
Demanganisation	2.70***	2.71***	2.70***	2.85***	2.93***	2.87***	2.91***	2.94***	3.96***
	(-0.92)	(-0.92)	(-0.92)	(-0.86)	(-0.85)	(-0.86)	(-0.85)	(-0.85)	(-0.61)
Filtration	0.43	0.45	0.45	0.46					
	(-0.64)	(-0.64)	(-0.64)	(-0.63)					
Chem. Disinfection	1.39**	1.47***	1.41***	1.42***	1.49***	1.40***	1.28***	1.38***	1.50***
	(-0.61)	(-0.51)	(-0.45)	(-0.45)	(-0.44)	(-0.43)	(-0.41)	(-0.40)	(-0.40)
Chlorine	4.79***	4.82***	4.87***	4.88***	4.87***	4.89***	4.93***	4.96***	4.94***
	(-0.99)	(-0.97)	(-0.93)	(-0.93)	(-0.93)	(-0.94)	(-0.94)	(-0.94)	(-0.94)
Iron Removal	1.08	1.1	1.11	1.12	1.28	1.31	1.33	1.34	
	(-0.86)	(-0.86)	(-0.86)	(-0.86)	(-0.82)	(-0.82)	(-0.82)	(-0.82)	
No Sludge Treat	-0.14	-0.12							
	(-0.45)	(-0.44)							
No Treatment	-0.15								
	(-0.61)								
Other Aggregation	1.94**	1.94**	1.95**	1.96**	1.94**	1.94**	1.67**	1.86**	1.82**
	(-0.78)	(-0.78)	(-0.78)	(-0.78)	(-0.78)	(-0.78)	(-0.74)	(-0.73)	(-0.73)
Other Technology	0.75	0.76	0.77	0.76	0.84	0.86	0.88		
	(-0.69)	(-0.69)	(-0.69)	(-0.69)	(-0.67)	(-0.67)	(-0.67)		
Potassium Permanganate	0.33	0.33	0.33						
	(-0.9)	(-0.9)	(-0.9)						
Radon Removal	-0.52	-0.49	-0.51	-0.52	-0.54				
	(-0.68)	(-0.66)	(-0.66)	(-0.66)	(-0.66)				
Sodium Hypochlorite	4.73***	4.74***	4.8***	4.79***	4.77***	4.77***	4.78***	4.8***	4.8***
	(-0.87)	(-0.87)	(-0.83)	(-0.83)	(-0.83)	(-0.83)	(-0.83)	(-0.84)	(-0.84)
Constant	11.98***	11.85***	11.81***	11.84***	12.01***	12.04***	12.11***	12.07***	11.82***
	(-1.46)	(-1.33)	(-1.31)	(-1.31)	(-1.29)	(-1.29)	(-1.28)	(-1.28)	(-1.26)
Number of observations	3 253	3 253	3 253	3 253	3 253	3 253	3 253	3 253	3 253
R2	0.08	0.08	0.08	0.08	0.082	0.082	0.081	0.081	0.08

Robust standard errors are given in parentheses *** $p < 0.01$, ** $p < 0.05$, * $p < 0.1$

PDVa	the amount of groundwater abstracted at the point *a*
SPD	rate of charges for the abstraction of groundwater
VVa	the amount of drinking water produced at the point *a*

Since CNa were not included in the database, we calculated them as:

$$CNa = JNa * VVa \tag{3}$$

where *JNa* are unit production costs (CZK/m3) listed in VÚPE database.

RESULTS

First, we estimated the full model including all explanatory variables, i.e., ln *VV*, *EL*, *PDV_d*, and *TECH 1–30*. As heteroskedasticity was detected (Breusch-Pagan test: F(16.32) = 5.35, Prob > F = 0.00), robust standard errors were calculated for all specifications.

The coefficients were statistically significant for ln *VV*, *EL*, *PDV_d* and some *TECH* (demanganisation, chemical disinfection, chlorine, other technologies, and sodium hypochlorite). To simplify the model, we successively dropped the variables with the lowest absolute value of the t-statistic. We proceeded in this way until only statistically significant variables remained. The variables were successively dropped in the following order: No Treatment, No Sludge Treat, Potassium Permanganate, Filtration, Radon Removal, Deacidification, Other Technology, and Iron Removal. A total of nine model specifications were tested and the results of all these specifications are shown in *Tab. 2, columns 1–9*. The same variables were statistically significant in all tested model specifications.

The results show that companies that produce drinking water mainly from groundwater have significantly lower production costs compared to companies that produce drinking water mainly from surface water. The size of this effect depends on model specification and ranges from 2.06 to 2.47. Furthermore, we confirmed economies of scale, as unit costs drop significantly with the logarithm of the amount of water produced. This finding was significant at the 1 % significance level in all specifications tested. It was also found that unit production costs increase slightly with unit consumption of electricity (by 0.5 CZK/m^3). Last but not least, we found that some water treatment technologies and the use of certain chemicals increase production costs. The biggest impact is the use of sodium hypochlorite (Sodium Hypochlorite), chlorine (Chlorine), and demanganisation (Demanganisation), which increase unit costs by 4.7–4.8 CZK, 4.8–4.96 CZK, and 2.7–3.96 CZK.

CONCLUSION AND DISCUSSION

In order to design cost-effective public water supply systems, it is essential to understand the factors affecting drinking water treatment costs. This article contributes to the existing literature by analysing the factors affecting drinking water production costs in the Czech Republic in 2018. The results showed that production of drinking water from groundwater is cheaper than production from surface water sources. However, some technologies increase drinking water treatment costs, so producing drinking water from groundwater can be more expensive than from surface water. Furthermore, we have confirmed economies of scale in drinking water production, which means that centralized water treatment is more cost-effective. A similar result (i.e. decreasing costs with the logarithm of the amount of drinking water produced) was also shown by previous studies [1, 9]. In further research, economies of scale could be further tested using different specifications of the cost model, e.g., translog or Cobb-Douglas function, as studied in previous studies [9].

The estimated cost function is based on the general cost function. However, data for some explanatory variables were not available, e.g., data on company characteristics and fixed production factors. We also had limited data on the costs of non-environmental inputs, e.g., missing data on the number of employees, ownership structure, and number of customers supplied. However, local specific factors have the greatest influence on drinking water production costs [1]; therefore, the lack of these data probably caused the low value of determination coefficient R2. The problem of these missing data could be overcome by using panel data, as fixed effects control for time-constant characteristics [10]. Using panel data will allow to take into account the heterogeneity between companies. When using a fixed-effects model, it is possible to distinguish the influence of time-invariant characteristics, such as company size and managerial characteristics, and time-varying characteristics, such as raw water quality and technologies used. Furthermore, although the database does contain raw water quality data, it was not possible to use this index as this data was missing or misreported in many observations.

In all estimated models, the R2 value was quite low (0.08). However, there is no assumption about the minimum R2 value in linear regression models. A low R2 value means that only a small part of the variability of the dependent variable is explained by the explanatory variables used [11]. In our case, the low R2 value was caused by site-specific factors that most influence drinking water production costs [1] and which were not included in the estimated cost function due to missing data. In subsequent further research, it is possible to supplement these data together with data on raw water quality and use them to estimate the cost function.

The results show that producing drinking water from groundwater is cheaper than production from surface water. This is due to the usually better quality of groundwater compared to surface water [3, 12] thanks to natural purification of groundwater, the so-called regulating ecosystem service of water purification. Despite the great importance of ecosystem services associated with groundwater, these services are often neglected in decision-making, which is mainly due to the fact that the value of these ecosystem services is difficult to express in monetary units [13]. The results of the presented study can be used to calculate the monetary value of purification of groundwater which is used to produce drinking water. The replacement cost method, which has already been used to value groundwater purification in the Netherlands [4, 14] and surface water [15], is suitable for valuation. To use this valuation method, it is necessary to know the difference in the production costs of drinking water from surface and groundwater sources, which was the content of this research.

In follow-up research, it would be appropriate to use panel data, which would alleviate the shortcomings caused by the absence of some variables affecting the costs of companies, such as the characteristics of water management companies. Furthermore, it is necessary to focus on research into the relationship between the production costs of drinking water and the characteristics of the catchment area of raw water abstraction points, such as the ratio of the representation of different ecosystems in a catchment area. The influence of ecosystems on the production costs of drinking water has already been addressed in numerous studies outside Central Europe, e.g. [8, 16, 17]. According to these studies, raw water is cleaner when abstracted from places whose catchment areas are dominated by forests. The costs of treating this water are lower compared to water that is abstracted from catchment areas where populated areas and agriculture predominate.

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