Validation of the Linear Trend Estimation Technique for Prediction of Average Water and Sewerage Charge Rate Prices in the Czech Republic

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***Abstract*—**The article deals with the issue of water and sewerage charge rate prices in the Czech Republic. The research is specifically focused on the analysis of the development of the average prices of water and sewerage charge rate in the Czech Republic in 1994-2021 and on the validation of the chosen methodology relevant for the prediction of the development of the average prices of water and sewerage charge rate in the Czech Republic. The research is based on data collection. The data for this research were obtained from the Czech Statistical Office. The aim of the paper is to validate the relevance of the mathematical linear trend estimate technique for the calculation of the predicted average prices of water and sewerage charge rates. The real values of the average prices of water and sewerage charge rates in the Czech Republic in 1994-2018 were obtained from the Czech Statistical Office and were converted into a mathematical equation. The same type of real data was obtained from the Czech Statistical Office for 2019-2021. Prediction of the average prices of water and sewerage charge rates in the Czech Republic in 2019-2021 was also calculated using a chosen method – a linear trend estimation technique. The values obtained from the Czech Statistical Office and the values calculated using the chosen methodology were subsequently compared. The research result is a validation of the chosen mathematical technique to be a suitable technique for this research.

***Keywords*—**Czech Republic, linear trend estimation, price prediction, water and sewerage charge rate.

I. Introduction

NOWADAYS, everyone is aware of the water scarcity issue. This occurs due to combination of many factors resulting in global warming and lack of rainfall. In the Czech Republic, wells and underground water sources are drying up. However, it is not only global warming that contributes to the loss of groundwater in the Czech Republic.

Thirty years ago, no one was thinking about whether there was enough water on Earth, whether it was managed efficiently or whether there would be enough water for future generations. Nowadays, nearly everyone is aware of the situation and the changes in nature that are taking place around us. It is, therefore, necessary to raise questions such as how to become water efficient, how to protect water and prevent its pollution, or what can be done to protect water sources.

When there is a shortage of goods or services in the market, this is reflected in an increase in the price of that goods or services. However, the price of water in the Czech Republic in particular is not driven only by the fact that it is becoming scarcer due to global warming. Drinking water and water drained through sewers is included in the list of goods with regulated prices, which is issued annually by the Ministry of Finance of the Czech Republic under the Prices Act and is available in the Price Bulletin. The price of water and sewerage charge rates can therefore include the economically justified costs of acquisition, processing and circulation of the goods, which are documented in the accounting records, as well as the tax, a reasonable profit (10-20%) and, if applicable, customs duties applied under different legislation, unless otherwise specified. In summary, the price of water consists of water charge rates, i.e., all costs associated with the production and distribution of drinking water, and sewerage charge rates, which include the costs of wastewater disposal and treatment. This way of price regulation sets the basic rules for determining the price; however, some responsibility is left to the individual owners of water supply and sewerage (WSS) systems. In the Czech Republic, the operation of WSS systems is a public service, which is therefore supplied to the citizens of the country, and since it is a public service, citizens should be able to pay for it, so the price should be acceptable to all citizens.

The price of water has been constantly rising according to the internet server eAGRI.cz and the Czech Statistical Office [1], [2]. While in 2010 the price of drinking water was 29.10 CZK/m^3 without value added tax (hereinafter: VAT) and the price of sewerage was 26.30 CZK/m^3 without VAT, in 2020 the price of drinking water rose to 41.40 CZK/m^3 without VAT and the price of sewerage rose to 36.50 CZK/m^3 without VAT. Even 2022 has been experiencing a considerable increase in the price of water and sewerage charge rates. Water companies attribute this to rising costs and the need to invest in infrastructure. The coronavirus pandemic has also had an impact on water price calculations since 2020. The war in Ukraine at the beginning of 2022 has triggered a new wave of a rapid increase in the price of products and services, so the increase in prices has affected and will continue to affect all sectors of the economy in the future. This concludes that the War in Ukraine will also have an impact on the price of water in the future, although it is currently impossible to predict to what extent.

At present and in the given situation, it is very difficult to

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estimate the development of water and sewerage charge rate prices in the Czech Republic in the future. However, some mathematical models can predict their course under appropriately set calculation conditions. For the purpose of this research, the Czech Statistical Office provided data on average water and sewerage charge rates in the Czech Republic for the 1990-2021 period in CZK/m^3 without VAT. Since until 1993 water and sewerage price rates were subsidized by the state budget, so it is appropriate to use just data from 1994 onwards for the purposes of this research. This shall eliminate possible distortions in the calculations. As water and sewerage price rates have been rising steadily throughout the period under review, it can be assumed that this will be the case in the future as well. It was necessary to choose an appropriate mathematical method for this increasing trend in the data. The mathematical technique of the linear trend estimation was chosen as the most appropriate technique in relation to the nature of the data (increasing trend) out of all mathematical models suitable for the prediction of data. This technique allows for predicting the development of water and sewerage charge rate prices in the Czech Republic for the forthcoming years (e.g., 2022-2025). Whether this technique is the most appropriate of all possible methods is necessary to be validated on already known data. Therefore, the data obtained from the Czech Statistical Office were split. The years 1994-2018 were used as the input data for the calculation. Using these data, the development of average water and sewerage charge rate prices for 2019-2021 in the Czech Republic was predicted using the chosen mathematical technique. The result was then a comparison of average water and sewerage charge rate prices in the Czech Republic obtained from the Czech Statistical Office and prices calculated using the chosen mathematical model. The appropriateness of using the chosen mathematical technique of the linear trend estimation for this research was also assessed.

The article focuses solely on a part of the research, namely on the comparison of average water and sewerage charge rate prices in the Czech Republic, which were obtained from the Czech Statistical Office and those determined using mathematical calculations, subsequently assessing the suitability of the chosen methodology.

II. Literature Review

Tsur declares in his article on "Optimal water pricing: accounting for environmental externalities", that "A pricing-based mechanism that implements the optimal water policy while accounting for environmental externalities is developed". The analysis is presented in the context of a comprehensive water economy, stressing the tradeoffs between water use in the provision of ecosystem services vs. other uses. A distinction is made between conveyed and instream environmental water, which turns out to have important policy implications [3]. In 2015, the issue of efficient water pricing was also addressed by Fridman [4].

Wait and Petrie discuss a comparison of water prices for public and private water companies in the United States. This study examined the relationship between the ownership structure of water companies and water price and other factors such as water source, population, population density, population growth trends, size of the area served, and drought conditions [5].

Long-term prediction of water demand is essential for the planning and management of a water supply system. The issue of water demand management is important to be addressed not only in arid areas. Understanding the importance and future evolution of factors affecting water demand is a key step in the ongoing planning for a reliable and sustainable water supply. In their study, Ashoori et al. looked into predicting water demand trends in Los Angeles, California [6].

Borhan et al. examined the relationship between polluted water and economic growth. They suggested the way how it is necessary to focus on encouraging investment in appropriate technologies, particularly sewerage systems and others [7].

Liu and Fukushige investigate in their article the technical efficiency of Japanese WSS services using data envelopment analysis (DEA). They used regression analysis to explore the interactions between the efficiencies of WSS services on both their prices and those of the other services. The results indicate a positive relationship between the efficiency of water supply services and the prices for sewerage services, but no relationship between the efficiency of sewerage services and the prices of water supply services [8].

Schleich and Hillenbrand focused their research on how household water demand responds to rising and falling prices. This research was carried out in Germany between 2007 and 2013 for almost 3,000 supply areas. In particular, the analysis distinguishes between periods of rising and falling in water and sewerage prices. The research showed that water demand responds asymmetrically to rising and falling prices. When prices are falling, the short-run price elasticity is not statistically different from zero, and the long-run price elasticity is estimated at around 12%. Additional results illustrate that employing average prices instead of marginal prices results in substantially overestimating the price elasticity [9].

As mentioned in the introduction, resources are diminishing due to global warming, so water should not be wasted or deliberately polluted. Efficient use of water resources requires internalizing all costs into the price of water, including environmental and resource costs. This issue was addressed in Kejser's article "European attitudes to water pricing: Internalizing environmental and resource costs" [10]. Reducing water consumption and reducing water loss in the water supply system have been addressed by Tabesh and Beigi [11].

Li et al., using the example of the Hubei province, carried out a research on water the resources pricing model under the water resources-economic high-quality development coupling system. The results show that Hubei province now is lagging in the development of water resources, and the current water price is far lower than assessed [12].

Different rules for water pricing apply around the world. As water is a state subject in India, an enormous variety of irrigation water pricing across the states is noticed. Parween et al. presented a paper in which they review the structures of water pricing mechanisms in different states of India and suggest a way of achieving sustainable water sources management in India [13].

The scarcity and degradation of water sources become one of the major environmental problems in Europe, which is being addressed by the Water Framework Directive, the Urban Waste Water Directive, and the Nitrates Directive. Albiac et al. undertook a study reviewing water policy instruments that might be more appropriate for achieving the objectives of the Water Framework Directive. The article highlights the need for combining instruments to deal with the public good, common pool source, and private good characteristics of water [14].

Oblouková in her article dealt with the development of water and sewerage price rates in the Czech Republic in 2010-2019. The aim was first to analyze the average water and sewerage price rates in the Czech Republic in the period under study, then to define the average water and sewerage price rates for individual regions. The methodology of horizontal analysis was chosen for data analysis. The analysis showed that the average price of water and sewerage charge rates in the Czech Republic has had a constantly increasing tendency, which can be expected in the forthcoming years [15].

Vítková et al. compared water and sewerage charge rate prices in the Czech Republic and macroeconomic indicators representing the performance of individual regions of the Czech Republic. The data were focused on 2007-2020. The research focused on the basic research question, namely whether "regions with lower macroeconomic performance have lower water and sewerage charge rate prices than regions with higher macroeconomic performance". The research concluded that there is no obvious equality between the price of water and sewerage charge rates and macroeconomic indicators in the regions of the Czech Republic. Therefore, further research should focus on establishing correlations between the price of water and sewerage charge rates, individual macroeconomic indicators and other technical indicators related to the operation of WSS systems, e.g., length of water supply connections and number of customers [16].

III. Input Data

The primary source of input data (average prices of water and sewerage charge rates in the Czech Republic) for the research was the Czech Statistical Office. This is the central governing body of the Czech Republic. It was established on 8 January 1969 by Act No. 2/1969 Coll., on the establishment of ministries and other central bodies of state administration. The Czech Statistical Office performs collection and processing of data for statistical purposes and provides statistical information to the state authorities, local authorities and the public as well as from abroad. It provides the comparability of statistical information at national and international levels. These input data were further checked for relevance on the eAGRI.cz website. This is a departmental portal of the Ministry of Agriculture, where (among other things) reports on the state of water management in the Czech Republic for the past years can be found.

The data were obtained over the last 32 years, i.e., from 1990 to 2021. Until 1993, the prices for water and sewerage charge rates were subsidized by the state budget, so it was appropriate to use data from 1994 onwards for this research. This eliminated possible distortions in the calculations. These data were used to determine the development of water and sewerage charge rate prices in the Czech Republic in the subsequent years. However, this research is aimed at validating the chosen methodology. Therefore, the research described in this article works only with data from 1994-2018. The remaining 3 years, i.e., 2019-2021, serve in this research to validate whether the chosen methodology was appropriate and can be used.

Table I shows the development of average water and sewerage charge rate prices in the Czech Republic in 1994-2021.

TABLE I
Development of Average Water and Sewerage Charge Rate Prices in CZK/M^3 in the Czech Republic for the Monitored Years

Year	Water and sewerage charge rate prices without VAT	Year	Water and sewerage charge rate prices without VAT
1990	3.89 CZK/m^3	2006	42.71 CZK/m^3
1991	4.72 CZK/m^3	2007	46.06 CZK/m^3
1992	6.06 CZK/m^3	2008	49.20 CZK/m^3
1993	11.95 CZK/m^3	2009	53.17 CZK/m^3
1994	16.00 CZK/m^3	2010	55.39 CZK/m^3
1995	17.93 CZK/m^3	2011	58.70 CZK/m^3
1996	20.75 CZK/m^3	2012	62.36 CZK/m^3
1997	22.73 CZK/m^3	2013	62.93 CZK/m^3
1998	25.50 CZK/m^3	2014	64.61 CZK/m^3
1999	29.08 CZK/m^3	2015	66.26 CZK/m^3
2000	31.51 CZK/m^3	2016	68.80 CZK/m^3
2001	33.26 CZK/m^3	2017	70.04 CZK/m^3
2002	35.35 CZK/m^3	2018	71.50 CZK/m^3
2003	37.71 CZK/m^3	2019	74.00 CZK/m^3
2004	38.87 CZK/m^3	2020	77.90 CZK/m^3
2005	40.60 CZK/m^3	2021	82.38 CZK/m^3

1 Euro = 25.00 CZK

IV. Methodology

The method chosen to determine average water and sewerage charge rate prices in the Czech Republic for 2019-2021 is called the linear trend estimation technique. It is one of the most common trend functions in time series analysis. A time series is a sequence of factually and spatially comparable data that are uniquely ordered in terms of time in the past-present direction.

The years 1994-2018 were chosen as input data. First of all, it was necessary to calculate and find a suitable linear function using the least squares method:

$$y = E[(Y(x)] = \beta_0 + \beta_1 x = \underbrace{(1\ x)}_{x^T} \underbrace{\begin{pmatrix}\beta_0 \\ \beta_1\end{pmatrix}}_{\beta} = x^T\beta = E[(Y(x^T)], k = 2, N = 25 \quad (1)$$

$$\hat{y}_x = \hat{E}[(Y(x)] = \hat{\beta}_0 + \hat{\beta}_1 x \quad (2)$$

where, $y = E[(Y(x)]$ is mean value of the average price of water and sewerage charge rate for a given year in CZK/m^3, β_0 and β_1 are parameters of the regression function, x is ordinal number of the given year, k is number of β parameters, N is number of input values or number of years monitored too, $x^T\beta$

is mean of the estimate, $\hat{y}_x = \hat{E}[(Y(x)]$ is estimate of the average price of water and sewerage charge rate in a given year in CZK/m³, $\hat{\beta}_0$, $\hat{\beta}_1$ are point estimates of the parameters of the regression function.

Assessing the appropriateness and adequacy of the linear estimation model using the multiple determination selection coefficient R2. R2 100% indicates the percentage of variability in the dependent variable that can be explained by the regression function. The closer it is to 1, the more appropriate the model is:

$$R^2 = 1 - \frac{Se}{Sc} \quad (3)$$

$$Se = \Sigma(\hat{y}_x - y_x)^2 \quad (4)$$

$$Sc = \Sigma\left(y_x - y_p\right)^2 \quad (5)$$

where, R^2 is multiple determination selection coefficient, Se is residual sum of squares, Sc is a total sum of squares, $\hat{y}_x$ is estimate of the average price of water and sewerage charge rates in a given year in CZK/m³, y_x is average water and sewerage charge rate price of the year in CZK/m³, y_p is average of the average water and sewerage charge rate prices for all years under consideration in CZK/m³.

All formulas and matrices were calculated in Microsoft Excel. The correctness of the calculations was validated by graphical method and using the Microsoft Excel function "data analysis". The above-mentioned formulas, (3)-(5), were subsequently used to calculate point estimates for 2019-2021, i.e., estimates of average water and sewerage charge rate prices in the Czech Republic in 2019-2021. These are the mean values of the estimates, which were subsequently supplemented with an interval estimate. This means that a range has been set for how much a given prediction of the mean can increase or decrease. For this research, a 99% interval estimate was chosen for 2019-2021 and it was calculated using the following formulas:

$$\Delta_E(x) = s\sqrt{f_x} = s\sqrt{x^T(X^TX)^{-1}x} \quad (6)$$

$$\Delta = \Delta_E t \quad (7)$$

$$t(N-k; 1-\frac{\alpha}{2}) \quad (8)$$

$$s^2 = \frac{Se}{(N-k)} \quad (9)$$

where, s^2 is unbiased estimate, Se is residual sum of squares, k is number of β parameters, N is number of input values or number of years monitored too, α is confidence level, Δ is absolute increase, $\Delta_E(x)$ is estimate of the standard deviation of the estimate, t is tabulated value of the quantile, f_x is estimation function, $x^T(X^TX)^{-1}x$ is product of matrices using the least squares method to calculate the estimation function.

V. RESULTS

The following conclusions were drawn on the basis of the above-stated data for the average water and sewerage charge rate prices in the Czech Republic, which were included in the research. All the outputs presented below were processed on the basis of the individual steps, namely data collection, data processing and data assessment using MS Excel. Firstly, the conclusions of the calculated regression function using time series analysis, specifically the linear trend estimation model were interpreted. Thus, an equation which, in the sense of the minimum of the sum of the squares of the deviations, approximates as closely as possible the course of the Y-covariance on $X_1, X_2, \ldots X_k$ was found. It resulted in:

$$\hat{y}_x = \hat{E}[(Y(x)] = 13.5778 + 2.4048x \quad (10)$$

TABLE II
SUMMARY OF THE CALCULATIONS FOR THE ESTIMATION OF THE MEAN VALUE OF THE AVERAGE WATER AND SEWERAGE CHARGE RATE PRICES IN CZK/M³ WITHOUT VAT IN THE CZECH REPUBLIC, INCLUDING CALCULATIONS FOR THE MULTIPLE DETERMINATION SELECTION COEFFICIENT R²

Year	x	y_x CZK/m³	$\hat{y}_x$ CZK/m³	$(\hat{y}_x-y_x)^2$	$(y_x-y_p)^2$
1994	1	16.00	15.98	0.00	831.78
1995	2	17.93	18.39	0.21	724.18
1996	3	20.75	20.79	0.00	580.36
1997	4	22.73	23.20	0.22	488.88
1998	5	25.50	25.60	0.01	374.06
1999	6	29.08	28.01	1.15	248.40
2000	7	31.51	30.41	1.20	177.79
2001	8	33.26	32.82	0.20	134.11
2002	9	35.35	35.22	0.02	90.07
2003	10	37.71	37.63	0.01	50.85
2004	11	38.87	40.03	1.35	35.65
2005	12	40.60	42.44	3.37	17.98
2006	13	42.71	44.84	4.54	4.54
2007	14	46.06	47.25	1.41	1.49
2008	15	49.20	49.65	0.20	19.00
2009	16	53.17	52.06	1.24	69.38
2010	17	55.39	54.46	0.86	111.29
2011	18	58.70	56.86	3.37	192.08
2012	19	62.36	59.27	9.55	306.93
2013	20	62.93	61.67	1.58	327.22
2014	21	64.61	64.08	0.28	390.83
2015	22	66.26	66.48	0.05	458.79
2016	23	68.80	68.89	0.01	574.05
2017	24	70.04	71.29	1.57	635.01
2018	25	71.50	73.70	4.83	710.72
Σ	325	1,121.02	1,121.02	Se = 37.23	Sc = 7,555.44
y_p	_	44.84	_	_	_
2019	26	74.00	76.10	4.43	850.27
2020	27	77.90	78.51	0.37	1,092.92
2021	28	82.38	80.91	2.15	1,409.20

1 Euro = 25.00 CZK

To predict the development of average water and sewerage charge rate prices in the Czech Republic for 2019-2021, it is sufficient to insert the values into the above-stated equation (10). The estimate of the mean value of the average price of water and sewerage charge rates in the Czech Republic is 76.10

CZK/m^3 for 2019, 78.51 CZK/m^3 for 2020 and 80.91 CZK/m^3 for 2021. These prices are without VAT. Subsequently, it was necessary to assess the suitability and adequacy of the linear trend estimation model. This assessment was performed using the multiple determination coefficient R^2. R^2 100% indicates what percentage of the variability of the dependent variable can be explained by the corresponding regression function. Simply put, the closer this coefficient is to 1, the more suitable the chosen technique is. In this research, the selection coefficient was equal to 99.41%, i.e., it was highly suitable.

The correctness of the results in Table II was validated using the graphical representation using Microsoft Excel. Thus, the estimated regression function was validated using a linear trend estimation and the calculation of the multiple determination selection coefficient R^2, see Fig. 1.

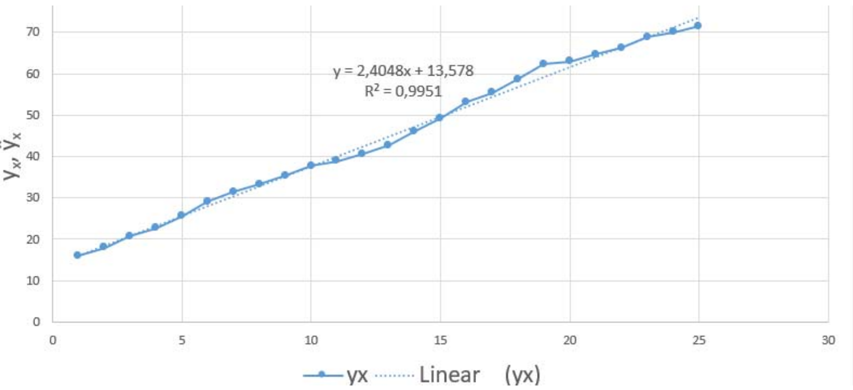

Fig. 1 Implementation of time series and its adjustment using a linear model

In Table III, the 99% interval estimate for 2019-2021 has already been calculated. It is clear for 2019 that the estimated average price of water and sewerage charge rates in the Czech Republic fall within the interval CZK 74.63-77.58/m^3, for 2020 CZK 76.95-80.07/m^3 and for 2021 CZK 79.26-82.56/m^3. The prices listed in Table III are without VAT.

TABLE III
UPPER AND LOWER BOUNDARIES OF THE MEAN VALUE ESTIMATE OF THE AVERAGE PRICE OF WATER AND SEWERAGE CHARGE RATES IN CZK/M^3 WITHOUT VAT FOR 2019-2021

Year	$x'(X'X)^{-1}$		$x'(X'X)^{-1}x$	$\Delta_E(x)$	Δ	$\hat{y}_x - \Delta$ CZK/m^3	$\hat{y}_x + \Delta$ CZK/m^3
2019	-0.09	0.01	0.17	0.52	1.47	74.63	77.58
2020	-0.10	0.01	0.19	0.56	1.56	76.95	80.07
2021	-0.11	0.01	0.21	0.59	1.65	79.26	82.56

1 Euro = 25.00 CZK

The result is a comparison of the average prices of water and sewerage charge rates in the Czech Republic obtained from the Czech Statistical Office and those calculated using the selected mathematical model which was a linear trend estimation. The absolute difference in values between the actual average price of water and sewerage charge rates in the Czech Republic and the price calculated using the mathematical model fall within the range of 0.61-2.1 CZK/m^3 without VAT. Thus, the percentage deviation from the data from the Czech Statistical Office was 2.84% in 2019, 0.78% in 2020 and 1.78% in 2021, which can be considered to be low values. This indicates an appropriate choice of mathematical method. At the same time, the actual values of average water and sewerage price rates of the Czech Republic for 2020-2021 fell within the calculated 99% interval estimate of average prices for these years. Only 2019 did not fit into the interval with 0.63 CZK/m^3 without VAT.

TABLE IV
COMPARISON OF ACTUAL AND ESTIMATED WATER AND SEWERAGE PRICE RATES IN THE CZECH REPUBLIC IN CZK/M^3 WITHOUT VAT FOR 2019-2021

Year	y_x CZK/m^3	$\hat{y}_x$ CZK/m^3	$\hat{y}_x - \Delta$ CZK/m^3	$\hat{y}_x + \Delta$ CZK/m^3	$\lvert\hat{y}_x - y_x\rvert$ CZK/m^3
2019	74.00	76.10	74.63	77.58	2.10
2020	77.90	78.51	76.95	80.07	0.61
2021	82.38	80.91	79.26	82.56	1.47

1 Euro = 25.00 CZK

VI. CONCLUSION

The main purpose of this research was to validate the use of the chosen technique for determining the development of average water and sewerage price rates in the Czech Republic in the forthcoming years. Available data from the Czech Statistical Office for 1994-2021 were used for the validation. First, the data were divided into input data and data to be validated by the chosen methodology. The input data were from 1994-2018, using the selected linear trend estimation technique the predict of the development of average water and sewerage price rates in the Czech Republic was carried out for 2019-2021. The result was a comparison of the data in 2019-2021 obtained from the Czech Statistical Office and those calculated using the selected linear trend technique and an assessment of the suitability of the selected mathematical technique of the linear trend estimate for use in this research.

According to the Czech Statistical Office, the average prices of water and sewerage charge rates in the Czech Republic in 2019-2021 were CZK 74.00/m^3, CZK 77.90/m^3 and CZK 82.38/m^3. The calculations show that the estimate of the average price of water and sewerage charge rates in the Czech Republic in 2019 was CZK 76.10/m^3, for 2020 CZK 78.51/m^3 and for 2021 CZK 80.91/m^3. Thus, there was a deviation from the actual value by 2.84% in the first estimated year, by 0.78%

in the second year and by 1.78% in the last year. At the same time, the actual values of average water and sewerage charge rate prices in the Czech Republic for 2020-2021 fell within the calculated 99% interval estimate of average prices for these years. Only 2019 did not fit into the interval by 0.63 CZK/m^3 without VAT. In order to validate the appropriateness of the methodology used, the multiple determination selection coefficient R^2 was calculated. Simply put, the more this coefficient is closer to 1, the more appropriate the chosen method is. In this research, the selection coefficient resulted to be equal to 99.41%, indicating that the chosen linear trend estimation technique is suitable for use in this research.

The validation of the linear trend model on already known data has positive results. Therefore, it can be concluded that the linear trend estimation technique is suitable for predicting the development of average water and sewerage charge rate prices in the Czech Republic in further research.

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