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VALUING GROUNDWATER QUALITY IN THE CZĘSTOCHOWA CASE STUDY (POLAND)

WYCENA WARTOŚCI WÓD PODZIEMNYCH W REGIONIE CZĘSTOCHOWY (POLSKA) – STUDIUM PRZYPADKU

Streszczenie

Niniejszy artykuł przedstawia wyniki badania preferencji społecznych mieszkańców w regionie częstochowskim w zakresie ochrony wód podziemnych. Zastosowano metodę wyboru dyskretnego (CE), oszacowano gotowość do zapłaty (WTP) za poprawę jakości wód podziemnych przez rozwój systemów kanalizacyjnych. Otrzymane wyniki wskazują na znaczącą WTP za poprawę jakości wód podziemnych. Gospodarstwa domowe są skłonne zapłacić 18,25 PLN (4,43 EUR) miesięcznie za obniżenie zanieczyszczenia do maksymalnego bezpiecznego poziomu określonego przepisami UE (zmniejszenie stężenia azotanów w wodach podziemnych do 50 $mg \cdot L^{-1}$). Wyniki pracy uzupełniają stale rosnącą literaturę na temat szacowania wartości zasobów wodnych i mogą być przydatne w analizach efektywności inwestycji, w wycenie kosztów i korzyści środowiskowych związanych z poprawą lub pogorszeniem stanu wód podziemnych, a także w dyskusji nad polityką cenową w zakresie opłat i cen za wodę i usługi wodne.

Słowa kluczowe: szacowanie wartości wód podziemnych, metoda wyboru dyskretnego, skłonność do zapłaty, jakość wód podziemnych

Numer klasyfikacji JEL: Q51, Q53, Q58

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Introduction

Groundwater is the main source of potable water in Poland accounting for more than 70% of water consumption. As a result, groundwater pollution can have immediate and far reaching consequences for the country. The latest assessment of groundwater quality conducted in 2015 by the Polish Hydrogeological Survey suggests that groundwater pollution is increasing. Results indicated poor chemical status in 25% and unaccepted quality in 10% of the examined points while in 7%, concentrations of nitrogen compounds exceeded drinking water standards.[1] Nitrogen compounds in groundwater are largely due to leaks of liquid wastes from septic tanks of households, not connected to the sewerage system.

In this paper we examine the public's preferences and willingness to pay (WTP) for measures aiming to the protection of groundwater resources in the Częstochowa aquifer. In particular we study preferences and WTP for extending the coverage of the sewerage network in order to decrease nitrate concentrations in the aquifer using a discrete choice experiment. Policies for achieving good quantitative and chemical groundwater status according to the Water Framework Directive (WFD) have to be evaluated in terms of their economic performance using cost-effectiveness or cost-benefit analysis. So far, in Poland sewerage investments were evaluated only by cost-effectiveness analysis. This paper aims to assist to the implementation of cost-benefit analysis in Poland in the context of the WFD by providing estimates of the benefits from groundwater improvement. In particular, this paper reports the results of a choice experiment study conducted in the Częstochowa region aiming to the estimation of the general public's willingness to pay for protecting groundwater quality.

There is an extensive international literature estimating WTP for reducing groundwater pollution in general and nitrate concentrations in particular using stated preference methods. The range of estimates reported in the literature is wide, depending among others on location, choice of method and study design. The results of selected European studies from the last 15 years will be presented below.

[1] D. Palak-Mazur, A. Kostka, A. Kuczyńska, K. Ścibior, *Interpretacja wyników monitoringu operacyjnego, ocena stanu chemicznego oraz przygotowanie opracowania o stanie chemicznym jednolitych części wód podziemnych zagrożonych nieosiągnięciem dobrego stanu według danych z 2015 r.*, Raport, Państwowy Instytut Geologiczny – Państwowy Instytut Badawczy, Warszawa 2016, p. 175.

1. Literature review – applications of stated preference methods to groundwater valuations

1.1. Groundwater valuation studies

Nijkamp and Travisi use a choice experiment method (CE) to estimate WTP for groundwater contamination in Milan, Italy. They calculate household WTP at 180 EUR_{2003} per year[2] to avoid the contamination of one percent of farmland soil and aquifer.[3]

Hasler et al. estimate households' WTP for groundwater conservation in Denmark using two methods: a contingent valuation (CV) and a choice experiment.[4] Results are: 96 EUR_{2004} (CV) and 255 EUR_{2004} (CE) per year.[5]

Aulong and Rinaudo conduct a contingent valuation survey to assess WTP for groundwater protection in the Upper Rhine Valley aquifer in France. Values are elicited for two scenarios consisting of restoring drinking water quality and eliminating all traces of polluting substances (restoration of natural quality). Households are willing to pay 42.6 EUR_{2007} per year for 10 years for restoring drinking water quality and 77 EUR_{2007} per year for 10 years for restoring natural water quality.[6]

Christianoni et al. analyze a case study near Thebes (Greece), where an alluvial aquifer is contaminated with metals (Cu and Cr) and nitrates above the acceptable safe concentrations. They apply CV method and estimate residents' WTP on average level 120–144 EUR_{2009} per household per year.[7]

Martinez-Paz and Perni examine the total economic value (TEV) of groundwater by an application of CV and Production Function Method (PFM). The Gavilan Aquifer (Spain) is used for agriculture purposes and also supplies a wetland with high biological, recreational and landscaping values. Assessed TEV of groundwater is 0.454 EUR_{2010} per $1m^3$ and includes the price of services provided

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[2] 15 EUR per month.

[3] P. Nijkamp, C. Travisi, *Willingness to Pay for Agricultural Environmental Safety: Evidence from a Survey of Milan, Italy, Residents*, FEEM Working Paper No. 100.04, 2004, p. 13.

[4] B. Hasler, T. Lundhede, L. Martinsen, S. Neye, J.S. Schou, *Valuation of Groundwater Protection versus Water Treatment in Denmark by Choice Experiments and Contingent Valuation*, NERI Technical Report No. 543, 2005, p. 90.

[5] Currency converter 1 DKK = 0,1344 EUR in 2004 by https://www.oanda.com.

[6] S. Aulong, J.-D. Rinaudo, *Assessing the Benefits of Different Groundwater Protection Levels. Results and Lessons Learnt from a Contingent Valuation Survey in the Upper Rhine Valley Aquifer, France*, 13th IWRA World Water Congress 2008, Monpellier, France, 2008, p. 5.

[7] M. Christantoni, G. Tentes, D. Damigos, *Groundwater Valuation: Testing the Transferability of Secondary Values*, in Proceedings of the Third International Conference on Environmental Management, Engineering, Planning and Economics, GrafimaPubl, 2011, p. 972.

by groundwater for: agriculture (0.381 EUR/m^3), recreation (0.010 EUR/m^3) and environmental functions (0.063 EUR/m^3).[8]

Tempesta and Vecchiato use a choice experiment to estimate the value of improving groundwater in the Serio River region in Italy, where reduction of the presence of nitrates in groundwater is necessary. Results of their multinomial logit model suggest that WTP lies between 50 and 90 EUR$_{2010}$ per household while a latent class model implied somewhat higher valuation.[9]

Tentes and Damigos examine the public's preferences for the restoration of the Asopos river basin in Greece, using CV in 2009 and CE in 2013. Using CV estimated WTP ranges between 180 and 239 EUR$_{2009}$ per year[10] while using CE households are willing to pay 909 EUR$_{2012}$.[11]

The next Greek case study with CE application is done by Latinopoulus. The municipality of Nea Propontida is experienced serious problems of water quantity and quality (identified high concentrations of nitrates, chlorides and arsenic). An average WTP is 95.7 EUR$_{2012}$ per year per household.[12]

Damigos et al. examine society's WTP for preserving and improving groundwater via Managed Aquifer Recharge programmes. The main results of the three CV surveys: the Greek case study (Lavrion case study combines several water problems: seawater intrusion, water scarcity, overexploitation, karst aquifers, etc.): a very conservative estimate of population's WTP would be around 50 EUR$_{2015}$ per household per year, and a relatively conservative estimate is of the order of 80 EUR$_{2015}$ per household per year;[13] the Italian case study (a problem with an overexploitation) – respectively 40 EUR$_{2015}$ and 70 EUR$_{2015}$,[14] and in Portugal (Algrave case study with agriculture groundwater nitrate contamination): 15 EUR$_{2015}$ and 25 EUR$_{2015}$ per household per year.[15]

Herivaux and Rinaudo conduct two original contingent valuation surveys in France and in Belgium. There is industrial pollution (brownfield) in the Belgian case study (Meuse alluvial aquifer in Liege region), while the French site (Lower

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[8] J.M. Martínez-Paz, A. Perni, *Environmental Cost of Groundwater: A Contingent Valuation Approach*, "International Journal of Environmental Research" 2011, Vol. 5, p. 611.

[9] T. Tempesta, D. Vecchiato, *Riverscape and Groundwater Preservation: A Choice Experiment*, "Environmental Management" 2013, Vol. 52, p. 1497.

[10] G. Tentes, D. Damigos, *The Lost Value of Groundwater: The Case of Asopos River Basin in Central Greece*, "Water Resources Management" 2012, Vol. 26, p. 161.

[11] *Iidem*, *Discrete Choice Experiment for Groundwater Valuation: Case of the Asopos River Basin, Greece*, "Journal of Water Resources Planning and Management" 2015, Vol. 141, p. 8.

[12] D. Latinopoulos, *Using a Choice Experiment to Estimate the Social Benefits from Improved Water Supply Services*, "Journal of Integrative Environmental Sciences" 2014, Vol. 11, p. 200.

[13] D. Damigos, G. Tentes, V. Emmanouilidi, M. Balzarini, T. Carvalho, *Demonstrating Managed Aquifer Recharge as a Solution to Water Scarcity and Drought*, Report of MARSOL Project Deliverable D15.3, 2016, p. 45.

[14] *Ibidem*, p. 60.

[15] *Ibidem*, p. 79.

Triassic Sandstone in Lorraine region) has the problem with over-exploitation. The average stated WTP is approximately 40 EUR_{2015}/household/year over 10 years.[16]

Brouwer et al. estimate public willingness to pay for groundwater with different quality levels in the Aveiro Quaternary Aquifer in Portugal. Households are asked how much they would be willing to pay for their most preferred groundwater quality level (the current situation, irrigation water quality, drinking water quality or a situation with natural background levels).[17] WTP is assessed at 45 EUR_{2016} per household and per year.[18]

1.2. Estimations of willingness to pay for improvements in water services

The case study presented in this paper concerns the estimation of WTP for the quality improvement of groundwater used as a source of potable water. The amelioration of groundwater quality will be achieved mainly through investments in sewage infrastructure. So the reference will be also the papers that seek to determine the WTP for the improvement of tap water quality or for other water services and infrastructure. Examples of such research may be the following works.

Birol and Das use CE method to estimate local public's willingness to pay for improvements in wastewater treatment in Chandernagore municipality in India. An average household is willing to pay 1,78 EUR_{2007}[19] per year for higher quality and quantity of treated wastewater to minimize the high levels of environmental and health risks in the Ganga river.[20]

In similar study Logar et al. assess public willingness to pay for the reduction of the environmental and health risks of micropollutants (MPs) by investment in municipal wastewater treatment plants. They apply a CE in a national online survey. The results indicate that the average WTP per household is 83 EUR_{2012}[21] annually for reducing the potential environmental risk of MPs to a low level.[22]

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[16] C. Hérivaux, J.-D. Rinaudo, *Integrated Assessment of Economic Benefits of Groundwater Improvement with Contingent Valuation*, [in:] *Integrated Groundwater Management*, eds. A.J. Jakeman, O. Barreteau, R.J. Hunt, J.D. Rinaudo, A. Ross, Springer, Cham 2016, p. 536.

[17] R. Brouwer, C.M. Ordens, R. Pinto, M.T. Condesso de Melo, *Economic Valuation of Groundwater Protection Using a Groundwater Quality Ladder Based on Chemical Threshold Levels*, "Ecological Indicators" 2018, Vol. 88, p. 299.

[18] 3.78 €/month.

[19] 8.36 Rs/month (Indian Rupee), currency converter 1 Rs = 0.0177 EUR in 2007 by https://www.oanda.com.

[20] E. Birol, S. Das, *Estimating the Value of Improved Wastewater Treatment: The Case of River Ganga, India*, "Journal of Environmental Management" 2010, Vol. 91, p. 2170.

[21] CHF 100, currency converter 1 CHF = 0.8297 EUR in 2012 by https://www.oanda.com.

[22] I. Logar, R. Brouwer, M. Maurer, C. Ort, *Cost-Benefit Analysis of the Swiss National Policy on Reducing Micropollutants in Treated Wastewater*, "Environmental Science & Technology" 2014, Vol. 48, p. 12503.

A series of studies on willingness to payment for water services improvements was conducted by Vasquez within various research teams. There are estimated WTPs:

- in Mexico (Parral city, 100 thousand inhabitants), using CV approach, WTP ranges from 40 to 169 EUR_{2008}[23] per year above their current water bill for safe and reliable drinking water services,[24]
- in Nicaragua (León – the second largest city of Nicaragua), CV method application, residents are willing to pay 39–42 EUR_{2009} per year for system reliability improvement and only 7.6 EUR_{2009} per year for better drinking water quality,[25]
- in Guatemala (San Lorenzo, 10 thousand inhabitants), CV method application, a median WTP is 42 EUR_{2012} per year[26] for improved municipal water services.This implies an increase in the average monthly water bill of more than 200%, equivalent to 1.5% of the average household income,[27]
- 2018 in Nicaragua (Nueva Vida, 8 thousand inhabitants), CE method application, a median WTP is 49.31 EUR_{2016} per year[28] for improved wastewater disposal services.[29]

In 2011 another estimation for Mexico was done, Rodriguez et al. use CV experiment to examine households' perception of water quality and willingness to pay for clean water in Mexico City. The average WTP for better potable water quality is 14.47 EUR_{2011} per year,[30] which is about 0.22% of the average family income in Mexico City.[31]

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[23] 54–230 Mexican Pesos per month, currency converter 1 peso = 0.0614 EUR in 2008 by https://www.oanda.com.

[24] W.F. Vásquez, P. Mozumder, J. Hernández-Arce, R.P. Berrens,*Willingness to Pay for Safe Drinking Water: Evidence from Parral, Mexico*, "Journal of Environmental Management" 2009, Vol. 90, p. 3397.

[25] 93.14–100 Cordobas per month for reliability and 18 Cordobas per month for better water quality, currency converter 1 NIO = 0.0352 EUR in 2009 by https://www.oanda.com; W.F. Vásquez, D. Franceschi, *System Reliability and Water Service Decentralization: Investigating Household Preferences in Nicaragua*, "Water Resources Management" 2013, Vol. 27, p. 4923.

[26] 36.20 quetzals per month, currency converter 1 quetzal = 0.0974 EUR in 2012 by https://www.oanda.com.

[27] W.F. Vásquez, *Willingness to Pay and Willingness to Work for Improvements of Municipal and Community-Managed Water Services*, "Water Resources Research" 2014, Vol. 50, p. 8011.

[28] 106.07 Cordobas per month, currency converter 1 NIO = 0.0387 EUR in 2016 by https://www.oanda.com.

[29] W.F. Vásquez, J. Alicea-Planas, *Unbundling Household Preferences for Improved Sanitation: A Choice Experiment from an Urban Settlement in Nicaragua*, "Journal of Environmental Management" 2018, Vol. 218, p. 481.

[30] 3.1 USD in the bimonthly water bill, currency converter 1 USD = 0.7779 EUR in 2011 by https://www.oanda.com.

[31] L. Rodríguez-Tapia, D. Revollo-Fernández, J. Morales-Novelo, *Household's Perception of Water Quality and Willingness to Pay for Clean Water in Mexico City*, "Economies" 2017, Vol. 5, p. 10.

Tussupova et al. examine the consumers' WTP for piped water supply using the CV method in the Pavlodar Region, Kazakhstan.[32] The mean WTP is estimated to be about 97 EUR_{2012} per household per year.[33]

To the best of our knowledge this is the first study estimating the value of benefits of the groundwater quality improvement in Poland. This paper also contributes to the narrow literature on valuation of benefits of measures for groundwater quality improvement by presenting an application of the choice experiment method in the Częstochowa case study in Poland.

2. Case study and empirical approach

2.1. The Częstochowa case study

The case study site is located in the southern part of Poland. Administratively it belongs to the Silesian Voivodeship. The case site is the recharge area of the Main Groundwater Reservoir No 326 (MGWB 326) that is called Częstochowa aquifer, named after the largest town lying on this area. Figure 1 presents the location of the aquifer in Poland. Groundwater is connected to rock formations varying in age that compose the Quaternary, Jurassic (MGWB 326), Cretaceous and Triassic multi-aquifer formations. The MGWB 326 aquifer system is divided into two sub-basins: MGWB 326 (S) located southeast of Częstochowa, with documented and approved disposable water resources of 4,220 $m^3\ h^{-1}$ on the area of 170 km^2, and MGWB 326 (N) located north of Częstochowa, with documented and approved disposable water resources of 8,900 m^3h^{-1} on the area of 570 km^2.[34] The Częstochowa aquifer serves as the main source of drinking water for the local population of approximately 335,000 inhabitants and the local economy which amounts to approximately 800 factories and enterprises.

[32] K. Tussupova, R. Berndtsson, T. Bramryd, R. Beisenova, *Investigating Willingness to Pay to Improve Water Supply Services: Application of Contingent Valuation Method*, "Water" 2015, Vol. 7, p. 3031.

[33] 1,590 KZT per month, currency converter 1 KTZ = 0.0051 EUR in 2012 by https://www.oanda.com.

[34] Z. Kaczorowski, G. Malina, J. Mizera, *Zintegrowany System Gospodarowania i Ochrony Zasobów Wodnych GZWP 326*, Wodociągi Częstochowskie, Częstochowa 2007, p. 17.

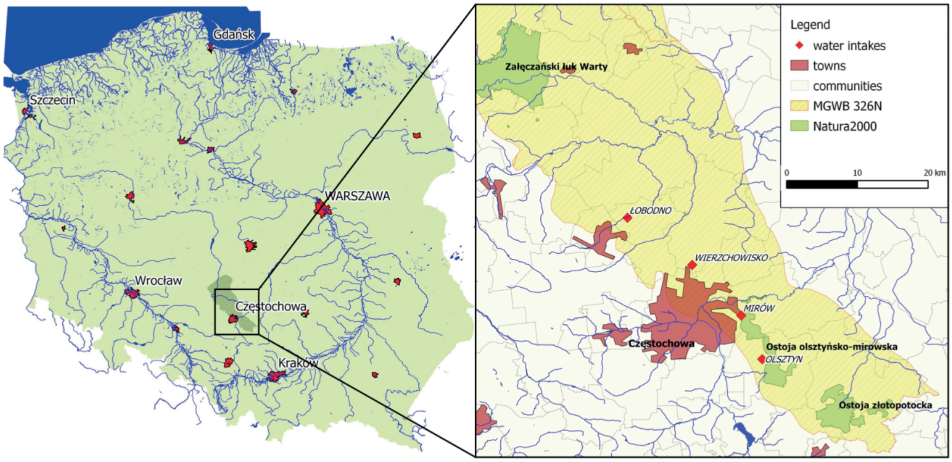

Figure 1. Location of Częstochowa case study – the Main Groundwater Reservoir No 326 (N) (MGWB 326N) with protected Natura 2000 areas and groundwater intakes

Source: own study.

The aquifer has very low resistance against pollutants originating from the terrain mainly because of lack of an insulation Quaternary layer. The reservoir is exposed on a considerable area and as a result is vulnerable to pollution. Over recent years an increase in of nitrate concentrations in a number of wells of currently used for drinking water supply has been observed. The mean annual NO_3^- concentration in extracted water in two wells of Łobodno water works has risen from 40 mg L^{-1} in 1997 to 60 mg L^{-1} in 2008. The permissible value for drinking water (50 mg L^{-1}) was exceeded in 2001 and the adverse concentrations of nitrates steadily increase (Fig. 2).[35]

Recent publications of Regional Inspectorate of Environmental Protection show that the quality of the MGWB 326 aquifer in wells of Łobodno water works continue to exceed the limit value of 50 mg L^{-1}. The mean annual NO_3^- concentration in 2014 and 2015 are respectively 64 and 60 mg L^{-1}. Water is classified as 4th class of unsatisfactory quality, in which the values of physico-chemical elements are increased as a result of natural processes in groundwater and the distinct impact of human activity.[36]

[35] J. Mizera, G. Malina, *Groundwater Extraction Control for Protecting the Water Works in Łobodno (SW Poland) against Contamination with Nitrates*, "Biuletyn Państwowego Instytutu Geologicznego" 2010, Vol. 441, p. 101.

[36] *Informacje o stanie środowiska w województwie śląskim w 2014 roku*, http://www.katowice.pios.gov.pl/index.php?tekst=monitoring/informacje/i [accessed: 29 June 2019]; *Informacje o stanie środowiska w województwie śląskim w 2015 roku*, http://www.katowice.pios.gov.pl/index.php?tekst=monitoring/informacje/i [accessed: 29 June 2019].

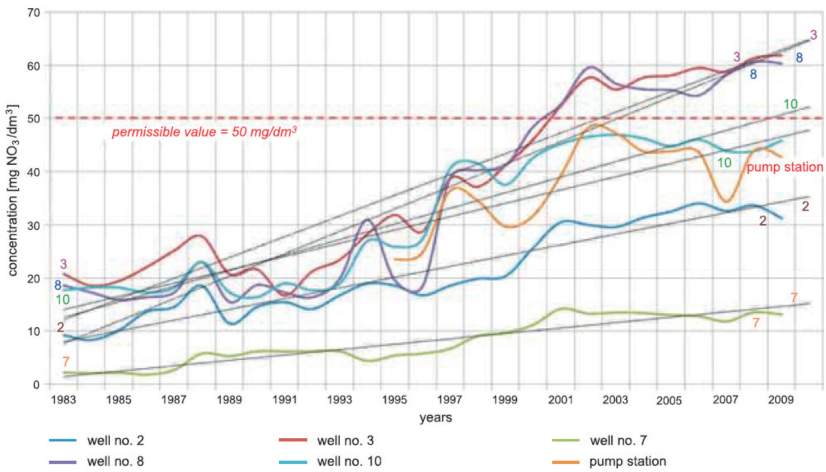

Figure 2. Changes of mean nitrate concentration in wells of Łobodno water intake

Source: J. Mizera, G. Malina, *Groundwater Extraction Control for Protecting the Water Works in Łobodno (SW Poland) against Contamination with Nitrates*, "Biuletyn Państwowego Instytutu Geologicznego" 2010, Vol. 441, p. 102.

The main cause of contamination is the limited coverage of the residential sewerage system. Figure 3 illustrates the variation in the share of the population connected to the sewerage system in communities in the case study area. In 2012, over 80% of the population was connected to the sewerage system in Częstochowa while just over 20% was connected in Rędziny. Overall, in most communities, less than 50% of population is connected to a sewage system while approximately 100,000 people use septic tanks.

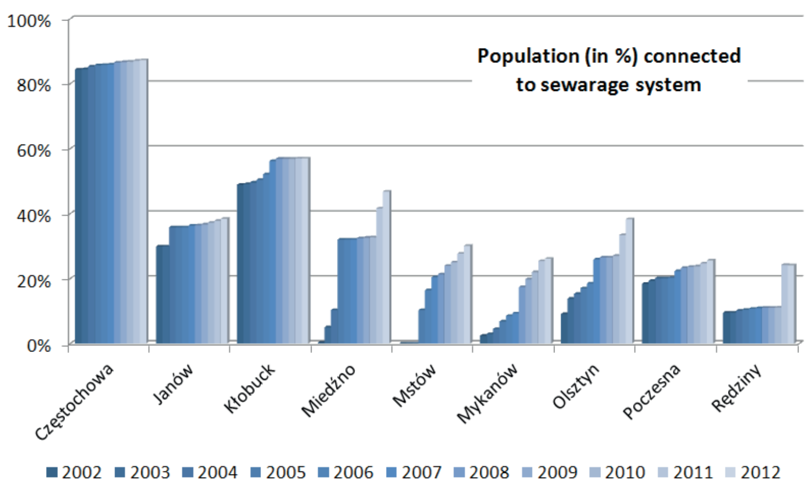

Figure 3. Equipping in sewerage systems in communities in the case study area

Source: own study based on BDL GUS, https://bdl.stat.gov.pl/BDL/dane/podgrup/temat.

In order to improve the groundwater quality a number of measures including the extension of sewerage systems and construction of wastewater treatment plants (WWTP) have been planned in communities in the case study area. Proposed development of infrastructure will allow 34 thousand of people to connect to sewerage and to treat additionally 620 m^3 of sewage per day. Capital expenditures of planned investments are shown in Table 1.

Table 1. Planned investments in sewerage systems and waste water treatment plants (WWTP) in the case study area

Community or association of communities		Planned-sewerage [km]	Increase in population connected to sewerage	Planned ratio of population connected to sewerage [%]	Costs [thousand PLN_{2010}]
Częstochowa, Mykanów, Rędziny, Poczesna, Konopiska		85.5	18,376	86.7	63,158
Rędziny		44.0	8,858	100.0	38,280
Kłobuck		29.7	4,578	88.9	35,664
Mstów		20.9	2,503	50.3	14,381
Mykanów		2.5	300	44.7	3,000
Total		182.6	34,615	85.6	154,483
Community	**Planned WWTP**		**Existing-capacity [m^3d^{-1}]**	**Planned-capacity [m^3d^{-1}]**	**Costs [thousand PLN_{2010}]**
Rędziny	WWTP construction		0	300	5,000
Kłobuck	modernization of WWTP		3,200	3,200	7,795
Mstów	extension of WWTP		320	640	2,000
Total			3,520	4,140	14,795

Source: own study based on https://www.kzgw.gov.pl/index.php/pl/materialy-informacyjne/programy/krajowy-program-oczyszczania-sciekow-komunalnych.

The cost of construction of sewerage systems is 154 million PLN_{2010}. These investments will made it possible to join the sewerage systems almost 35 thousand inhabitants. The investment cost per capita is 4.5 thousand PLN. Taking to account the average number of persons in household in Silesian Voivodship (2.6 person per household) total cost per household is approx. 12 thousand PLN.

3. Choice experiment design

To estimate the benefits from groundwater quality improvements we applied a stated choice experiment. The choice experiment (CE) method belongs to the family of stated preference methods. CE method examines individuals' preferences for changes in the quantity or quality of environmental resources by asking them to state their preferences for alternative hypothetical choice scenarios.[37] This method is based on Lancaster's characteristic theory of value and random utility theory.[38] According to the random utility model, the individual i has utility U_{ij} by choosing the alternative j. Respondent's choice is influenced by the attributes of the good (vector **x**), the price of alternatives (vector **p**), and the socioeconomic characteristics of the respondent (vector **Z**):[39]

$$U_{ij} = U(\mathrm{x}_j, \mathrm{p}_j, \mathrm{Z}_i) \tag{1}$$

where:
x_j – is the attribute of the good (the alternative j),
p_j – is the price of alternative j,
Z_i – is the socioeconomic characteristics of the individual i.

Utility U_{ij} can be expressed with an equation:[40]

$$U_{ij} = V_{ij} + \varepsilon_{ij} = \mathrm{x}_{ij}\beta + \varepsilon_{ij} \tag{2}$$

where:
V_{ij} – is the systematic part of utility,
ε_{ij} – is the random component,
x_{ij} – are the observed variables that relate to the alternative j and the individual i,
β – is a vector of the parameters.

[37] I. Logar, R. Brouwer, M. Maurer, C. Ort, *op. cit.*, p. 12501; E. Birol, S. Das, *op. cit.*, p. 2165.

[38] D. Latinopoulos, *op. cit.*, p. 189; E. Birol, K. Karousakis, P. Koundouri, *Using Economic Valuation Techniques to Inform Water Resources Management: A Survey and Critical Appraisal of Available Techniques and an Application*, "Science of The Total Environment" 2006, Vol. 365, p. 109.

[39] D. Andreopoulos, D. Damigos, F. Comiti, C. Fischer, *Estimating the Non-Market Benefits of Climate Change Adaptation of River Ecosystem Services: A Choice Experiment Application in the Aoos Basin, Greece*, "Environmental Science & Policy" 2015, Vol. 45, p. 93.

[40] *Ibidem*, p. 94.

The probability P_{ij} that an individual $i$will select alternative j over alternative p is given by:

$$P_{ij} = \Pr(U_{ij} > U_{ip}) = \Pr(\varepsilon_{ip} < \varepsilon_{ij} + V_{ij} - V_{ip} \forall p \neq j) \quad (3)$$

The most popular choice models are the multinomial logit and random parameter models.

3.1. Multinomial logit model

Multinomial logit model (MNL) is the most widely used model of multinomial unordered choices.[41] In MNL model, it is assumed that the random component has the Weibull's or Gumbel's distribution. Assuming that the error is Gumbel distributed implies MNL model:

$$P_{ij} = \frac{\exp(x_{ij}\beta)}{\sum_P \exp(x_{ip}\beta)} \quad (4)$$

MNL model has a canonical assumption that the choice sets must comply with IIA property (the independence of irrelevant alternatives), which states that ratios of choice probabilities are independent of the choice set.[42] The IIA property is most commonly validated by the test of Hausman and McFadden.[43]

3.2. Random parameter logit model

The restrictive assumption about IIA property often is not respected in the choice data. If the IIA property is violated then another discrete choice model that does not require the IIA property should be applied, such as the random parameter logit (RPL).

One important difference between multinomial logit and random parameter logit models is that the coefficient vector β in RPL is allowed to vary among

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[41] M. Gruszczyński, M. Bazyl, *Mikroekonometria: Modele i metody analizy danych indywidualnych*, Wolters Kluwer Polska,Warszawa 2012, p. 192; A. Bąk, *Mikroekonometryczne metody badania preferencji konsumentów z wykorzystaniem Programu R*, C.H. Beck, Warszawa 2013, p. 105; W. Greene, *Discrete Choice Modeling*, Palgrave Handbook of Econometrics, Palgrave Macmillan UK, London 2009, p. 538.

[42] A. Bąk, *op. cit.*, p. 107.

[43] S. Nakano, K. Nishimura, *Marginal Value Estimation for the Attributes of the Tameikes via Choice Experiment*, "Water Resources Management" 2014, Vol. 28, p. 67.

individuals instead of being fixed as in the MNL model.[44] So in RPL model, systematic part of utility V is dependent on the parameters β:

$$U_{ij} = V_{ij}(\beta) + \varepsilon_{ij} = x_{ij}\beta_i + \varepsilon_{ij} \tag{5}$$

The vectors β's have density functions $f(\beta|\theta)$ with characteristic parameters θ. In practice, β is assumed to have a normal distribution. RPL model is defined as follows:

$$P_{ij} = \int \frac{\exp(x_{ij}\beta)}{\sum_P \exp(x_{ip}\beta)} f(\beta|\theta) d\theta \tag{6}$$

3.3. Marginal WTP

On the basis of discrete choice experiments, the marginal willingness to pay MWTP for each non-monetary attribute can be calculated as the ratio of the utility coefficient of the attribute over the coefficient of the monetary attribute (payment).[45]

$$\text{MWTP} = -\frac{\beta_{\text{attribute}}}{\beta_{\text{payment}}} \tag{7}$$

where:
$\beta_{\text{attribute}}$ is the estimated coefficient of each attribute,
β_{payment} is the estimated coefficient for monetary attribute.

3.4. Total WTP

The sample mean WTP estimated in the survey may be aggregated to account for the total willingness to pay by multiplying mean WTP and population of beneficiaries (for example persons who live within the local water company area).[46] Total WTP can be calculated by the following equation:

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44 L.C. Rodrigues, J.C. van den Bergh, M.L. Loureiro, P.A.L.D. Nunes, S. Rossi, *The Cost of Mediterranean Sea Warming and Acidification: A Choice Experiment Among Scuba Divers at Medes Islands, Spain*, "Environmental and Resource Economics" 2016, Vol. 63, p. 298.

45 Y. Che, W. Li, Z. Shang, C. Liu, K. Yang, *Residential Preferences for River Network Improvement: An Exploration of Choice Experiments in Zhujiajiao, Shanghai, China*, "Environmental Management" 2014, Vol. 54, p. 522.

46 J. Loomis, P. Kent, L. Strange, K. Fausch, A. Covich, *Measuring the Total Economic Value of Restoring Ecosystem Services in an Impaired River Basin: Results from a Contingent Valuation Survey*, "Ecological Economics" 2000, Vol. 33, p. 114; I.J. Bateman, B.H. Day, S. Georgiou, I. Lake, *The Aggregation of Environmental Benefit Values: Welfare Measures, Distance Decay and Total WTP*, "Ecological Economics" 2006, Vol. 60, p. 451.

$$\mathrm{WTP}_a = N_a \mathrm{WTP} \tag{8}$$

where:
WTP_a – denoting total WTP in year a,
N_a – is the population of beneficiaries in year a,
WTP – is the mean willingness to pay.

3.5. Survey

The survey was tested prior to implementation. Data collection took place using face-to-face interviews from trained interviewers. We collected a random sample of 150 respondents (from different households). Data collection took place during July 2011. Overall 47 protest responses were identified through the use of debriefing questions and were removed from the final dataset. Protest responses are cases where respondents do not accept payment vehicle at all, refuse hypothetical payments, and are removed from the data set as opposed to zero-responses, i.e. responses that state about a maintained *status quo* and payments at level 0.[47]

The purpose of the choice experiment was to investigate the public's WTP for improving groundwater quality by investing on the improvement of municipal sewerage infrastructure, in the context of a groundwater management program. Motivated by the particular conditions in Częstochowa we characterised the management program in terms of three attributes. These were water quality, time to improvement and an additional monetary charge in the form of an additional lump sum payment on the water bill. We report the attributes and their levels in Table 2.

Water quality referred to the concentrations of pollutants in the groundwater. As mentioned earlier the main concern in the region is nitrate pollution. For the definition of the levels of the water quality attribute we relied on the characterisation of good ecological status of water resources according to the Water Framework Directive (WFD). The best possible level of water quality was "near zero" pollution. This was intended to reflect a state in which groundwater is not contaminated at all, which is the desirable condition according to the WFD. The second best level was pollution at the maximum permissible level by EU regulations, which is currently set at 50 $mg \cdot L^{-1}$. If no measure was implemented to mitigate water pollution, nitrate concentrations would exceed the maximum permissible level by 20%.

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[47] M. Czajkowski, A. Bartczak, O. Markiewicz, A. Markowska, J. Melichar, M. Scasny, H. Skopkova, *Lake Water Quality Valuation-Benefit Transfer Approach vs. Empirical Evidence*, "Ekonomia" 2007, Vol. 19, pp. 161–162; *Environmental Valuation in Developed Countries: Case Studies*, ed. D.W. Pearce, Edward Elgar Publishing, Northampton, MA 2006, p. 304.

The levels for the time-to-improvement attribute were 15, 20, 25 and 30 years. Due to the nature of water pollution fast improvement of water quality is unrealistic. The attribute was therefore included to examine whether the general public is willing to pay more for speedier resolution of the environmental quality issues. If no measure was implemented nitrate concentrations would exceed the maximum permissible level by 20% in 60 years. As a result, we selected the levels for this attribute to indicate improvement in the medium and long run.

The levels for the additional charge attribute were 20, 40, 50, 60, 80 and 100 PLN_{2011} (4.85, 9.71, 12.14, 14.56, 19.42, 24.27 EUR_{2011}).[48] The charge would be collected through the monthly water bill and all money collected would be exclusively used for the aquifer conservation plan. Respondents were informed that the project would be designed and implemented by the national government in order to increase the credibility of the survey.

Table 2. Attributes and levels used in the Choice Experiment (Status quo levels in italics)

Attribute	Levels
Nitrate pollution	three levels: Near zero pollution; Pollution at the maximum safe level; *Pollution 20% higher than the safe level*
Time to improvement	four levels: 15, 25, 30 and *60 years*
Additional water charge	seven levels: 20, 40, 50, 60, 80, 100 and *0* PLN_{2011}

Based on these attributes and their levels we constructed a d-efficient experimental design. Each respondent was asked to make 7 consecutive choices between 2 opt in and 1 zero cost opt out alternative. To avoid systematic starting point bias we randomized the presentation order of the choice sets. Table 3 presents an example of a choice card.

Table 3. An example of a choice card

Suppose that the three alternatives below are the only ones that are available for the management of the Częstochowa Aquifer. Which one of those would you choose if you had the choice?			
	Alternative 1	**Alternative 2**	**Alternative 3**
Nitrate pollution	Near zero pollution	Pollution at the maximum safe level	Pollution 20% higher than the safe level
Time to improvement	20 years	30 years	Deterioration in 60 years
Additional charge	80 PLN	50 PLN	0 PLN
I would choose Alternative:	1	2	3

[48] The average exchange rate in 2011 when the survey was conducted EUR 1 = PLN 4.1198.

The survey comprised three parts. The first part introduced the purpose of the research along with the importance of the Częstochowa aquifer for the region's domestic water supply. The second part of the survey described the current state of the aquifer in terms of water quality while it summarized the conditions that were expected to prevail in the future. It proceeded to outline the specific measures that would be implemented in order to improve water quality. After presenting valuation scenario and assuring the confidentiality of the responses, the respondents were asked to answer the survey questions while keeping in mind their budget constraints, financial obligations and other payments they make for similar goods and services. The choice sets were followed by a set of debriefing questions aiming to identify protest responses. The third part of the survey collected standard socioeconomic variables including employment status, education level and age.

4. Results and discussion

4.1. Multinomial Logit (MNL) models

Table 4 reports the results from a Multinomial Logit Model to analyze the determinants of stated individual choice. All attributes appear to be significant determinants of individual choice and carry the expected signs. Specifically, respondents are more likely to select alternatives with near-zero pollution and pollution at the safe level relative to alternatives with increased pollution. The sign of the time to improvement attribute is negative, indicating that respondents are less likely to select alternatives where the improvement will take place further into the future. The negative sign on the coefficient of the additional charge attribute implies that, as predicted by economic theory, respondents are less likely to select more expensive alternatives. Finally, the negative sign on the alternative specific constant suggests that respondents are less likely to select the status quo alternative relative to alternatives suggesting an improvement in water quality.

Table 4. Results of the Multinomial Logit Model

Attribute		Coefficient	St Error
Nitrate pollution	Near zero	1.377***	0.163
	Safe	1.176***	0.136
Time to improvement		-0.025**	0.013
Additional charge		-0.031***	0.003
Alternative Specific Constant		-1.976***	0.337
Log Likelihood		-666.101	
Observations		721	

*** Significanceat 1% level
** Significanceat 5% level

Table 5 reports the WTP estimates of the multinomial logit model. We estimate WTP for the attributes and their levels. Respondents are willing to pay 44.42 PLN (10.78 EUR) per household per month to achieve near zero nitrate pollution and 37.94 PLN (9.21 EUR) per household per month for pollution to remain at the maximum safe level according to EU regulations. Finally respondents are WTP 0.81 PLN (0.20 EUR) per household per month to reduce the delay in improving water quality by one year.

Table 5. Willingness to pay estimates

Attribute	WTP [PLN]
Nitrate pollution – near zero pollution	44.42 (36.76–54.71)
Nitrate pollution – at safe level	37.94 (34.71–49.97)
Time to improvement	0.81 (-0.02–1.58)

95% confidence intervals calculated using the Krinsky and Robb method[49] in parentheses

The confidence intervals of WTP estimates reported in Table 5 for the "near zero" and "safe" pollution levels overlap. This suggests the possibility that respondents did not distinguish between the two levels of the water quality attribute. We test whether this is true using the complete combinatorial method proposed by Poe et al.[50] and find that the test cannot reject the null hypothesis of equality between the mean WTP for "near zero" and "safe" pollution (*p*-value 0.173). It is therefore possible that respondents were concerned with maintaining adequate water quality but were insensitive to further improvements. This is also consistent with the findings from Poe[51] and Poe and Bishop[52] suggesting that households may engage in averting behaviour when exposure approaches threshold levels resulting to conditional benefit functions that may be non-convex around these thresholds. We investigate how this affects the results by estimating a MNL model after pooling the two levels of the water quality attribute, and report the estimates in Table 6.

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[49] A.R. Hole, *A Comparison of Approaches to Estimating Confidence Intervals for Willingness to Pay Measures*, University of York, Centre for Health Economics, CHE Research Paper 8, 2006, pp. 5–6.

[50] G.L. Poe, K.L. Giraud, J.B. Loomis, *Computational Methods for Measuring the Difference of Empirical Distributions*, "American Journal of Agricultural Economics" 2005, Vol. 87(2), p. 357.

[51] G.L. Poe, *Valuation of Groundwater Quality Using A Contingent Valuation Damage Function Approach*, "Water Resources Research" 1998, Vol. 34(12), p. 3632.

[52] G.L. Poe, R.C. Bishop, *Valuing the Incremental Benefits of Groundwater Protection when Exposure Levels are Known*, "Environmental and Resource Economics" 1999, Vol. 13(3), p. 357.

Table 6. Results of the Multinomial Logit Model merging quality levels

Attribute	Coefficient	St Error
Nitrate pollution (improvement)	1.241***	0.127
Time to improvement	-0.023*	0.0126
Additional charge	-0.029***	0.003
Alternative Specific Constant	-1.868***	0.327
Log Likelihood	-667.027	
Observations	721	

*** Significance at 1% level
* Significance at 10% level

The results are qualitatively similar to those presented earlier. Respondents are more likely to choose alternatives with improved water quality. They are also more likely to select alternatives where the improvement will be achieved sooner rather than later.

Table 7 reports the WTP estimates and the corresponding confidence intervals. WTP estimates are very similar to the ones reported in Table 5. Specifically, respondents are willing to pay 42.79 PLN per household per month for improving environmental quality relative to the status quo and 0.79 PLN per household per month to speed up the improvement.

Table 7. Willingness to pay estimates

Attribute	WTP [PLN]
Nitrate pollution – improvement	42.79 (34.71–52.13)
Time to improvement	0.79 (-0.02–1.58)

95% confidence intervals calculated using the Krinsky and Robb method in parentheses

The MNL model relies on the independence of irrelevant alternatives assumption (IIA). We test whether the IIA assumption holds using Hausman tests. The null hypothesis of IIA is rejected in one case while the test statistic is negative in 2 cases. The test results therefore suggest that the IIA assumption is not supported. Given this, we estimate Random Parameter Logit (RPL) models to account for unobserved individual preference heterogeneity, specifying that the parameters on all attributes are random, following the normal distribution.

4.2. Random Parameter Logit (RPL) models

The RPL model estimates are reported in Table 8 while the corresponding WTP values in Table 9. The RPL model results suggest that "time to improvement" is no longer a significant determinant of choice. Estimated WTP values are now smaller compared to the case of the MNL model. Households are willing to pay 19.79 PLN (4.80 EUR) per month to achieve near zero nitrate pollution and 18.25 PLN (4.43 EUR) per month for pollution to remain at the maximum safe level according to EU regulations.

Table 8. RPL model results

Attribute		Coefficient	St Error
Nitrate pollution	Near zero	1.521***	0.244
	Safe	1.300***	0.192
Time to improvement		-0.024	0.017
Additional charge		-0.053***	0.010
Alternative Specific Constant		-3.671***	0.747
Derived st. dev. of parameter distributions			
Nitrate pollution	Near zero	0.339	2.156
	Safe	0.009	0.653
Time to improvement		0.001	0.050
Additional charge		0.045***	0.012
Log Likelihood		-657.2969	
Observations		721	

*** Significanceat 1% level

Table 9. Willingness to pay estimates from the RPL model

Attribute	WTP [PLN]
Nitrate pollution – near zero pollution	19.79 (3.68–32.27)
Nitrate pollution – at safe level	18.25 (8.45–25.71)
Time to improvement	-0.30 (-0.85–(-0.21))

95% confidence intervals calculated using the Krinsky and Robb method [47] in parentheses

WTP estimates obtained with the help of RPL models for the improvement of the groundwater quality level – annually PLN 219–237 per household (53–58 EUR) are fairly comparable to those obtained in other European studies mentioned in the literature review (Brouwer et al. 45 EUR in Portugal,[53] Herivaux

[53] R. Brouwer, C.M. Ordens, R. Pinto, M.T. Condesso de Melo, *op. cit.*, p. 299.

and Rinaudo 40 EUR in France and Belgium,[54] Damigos et al. 50–80 EURO in Greece, 40–70 EUR in Italy and 15–25 EUR in Portugal[55]).

It is also very important to refer the estimated WTP values to the average water bills paid by households in case study area. The average annual household water bill is PLN 670 (PLN 56 per month) in the case study area, assuming that:

- average annual water consumption: 36 m^3 per person,[56]
- number of people in the household at the level of 2.6 people,[57]
- water prices: 3.32 PLN per 1 m^3 of supplied water and 4.84 PLN per 1 m^3 of treated wastewater,[58]
- households transport 80% of wastewater from their septic tanks to the wastewater treatment plants (some of the tanks are leaking and wastewater penetrates into the ground or is discharged into ditches, watercourses etc.); in the area of Mykanów community the average amount of treated wastewater is about 80% of the water supplied.

Estimated WTP shows that households are willing to pay 31–34% above their current water bills to improve of groundwater quality in Częstochowa Aquifer which is the main source of potable water for the region. A comparison of current water bills to household income allows the analysis of water affordability. An average household income is 3,160 PLN per month, so the current share of household expenditures on the purchase of water services is 1.76%. The affordability index for the case study is at a higher level than in the European countries (Italy – 0.3%, Austria – 0.4%, Sweden – 0.5%, France – 0.7%, the Czech Republic – 0.9%, Denmark – 1.1% and Hungary – 1.2%).[59] The high level of the water aff ordability index in Poland in comparison to western countries is explained by the low purchasing powerof Polish households incomes. Taking into account the additional payment resulting from the estimated WTP household expenditures on water bills may rise to 900 PLN resulting in growth of water aff ordability index to the level of 2.35%. This means a signifi cant approaching to the threshold value, which is 3%,[60] but it still does not cause it to be exceeded.

[54] C. Hérivaux, J.-D. Rinaudo, *op. cit.*, p. 536.

[55] D. Damigos, G. Tentes, V. Emmanouilidi, M. Balzarini, T. Carvalho, *op. cit.*, pp. 45, 60, 79.

[56] 99 L per person per day – the average water consumption according to the information of the Water Supply and Sewerage Company of the Częstochowa District (PWiK Częstochowa), https://www.pwik.czest.pl/zuzycie-wody.

[57] The average number of persons in household in Silesian Voivodship.

[58] Water ratesby PWiK Częstochowa in 2011.

[59] *Pricing Water Resources and Water and Sanitation Services*, OECD Studies on Water, OECD Publishing, 2010, p. 74.

[60] *Ibidem*, p. 76.

4.3. Total WTP

We calculate total WTP estimates (TWTP) by multiplying a sample mean WTP by the population within the area of communities where investments are planned (listed in Tab. 1). In such way the public willingness to pay for groundwater quality improvement by investing on sewerage is examined and the total value of improvement measures could be assessed. The population connected to the water supply network is almost 300 thousand people. The number of inhabitants is converted into the number of households, because the WTPs are estimated as a monthly payment per household. We take into account the average number of persons in household in Silesian Voivodship (2.6 person per household), so there are more than 115 thousand households in the case study area.

If it is assumed that a sample mean WTP is 18.25 PLN (4.43 EUR) per month, the total willingness to pay would exceed 25 million PLN per year. It means that the total investment cost (169 million PLN) are at the level of the total public willingness to pay from 7 years. Results of analysis allow to assess that planned measures (investments in sewage systems) can be financed from public funds in line with the public willingness to pay. The favorable result of the comparison of these two figures may be an argument in the discussion on the social acceptance of public expendituresin the context of serious financial constraints.

Conclusions

In this paper we present the results of a choice experiment aiming to evaluate the public's preferences for groundwater quality in the Częstochowa region in Poland. We used three attributes: water quality, time to improvement and an additional monetary charge in the form of an additional lump sum payment on the water bill.

Two the most widely used models of multinomial unordered choices are estimated: the multinomial logit (MNL) and random parameter (RPL) models. First, we use MNL model to estimate WTP for the attributes and their levels. However,the MNL model relies on the independence of irrelevant alternatives assumption (IIA). This restrictive assumption about IIA property often is not respected in the choice data andthis was the case of our survey. Because the IIA property is violated we use RPL model that does not require the IIA property should be applied. Finally, the RPL model results suggest that "time to improvement" is not a significant determinant of choice. Households are willing to pay 19.79 PLN (4.80 EUR) per month to achieve near zero nitrate pollution and 18.25 PLN (4.43 EUR) per month for pollution to remain at the maximum safe level according to EU regulations.

The results indicate that there is substantial WTP for water quality improvements that can be achieved through investment in infrastructure. Our results add to the expanding literature on the valuation of water quality in Poland and in Europe and can be useful for water management and for the policy debate, especially in the context of the EU's Water Framework Directive and Groundwater Directive. The present lack of information on the public preferences for improved ground water quality and water investments is an obstacle to building a proper water policy in Poland. The household preferences in the form of willingness to pay and the total WTP for improvement measures provide the necessary information forcorrect pricing and investment policies.Results of analysis allow for:

- assessing whether measures planned are not disproportionately expensive in comparison to the public willingness to pay,
- selecting economically justified measures,
- developing socially acceptable water prices.

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Abstract

This paper presents results of the study on preferences of inhabitants of the Częstochowa Region in Poland in the field of groundwater protection. The choice experiment (CE) method was applied, and willingness to pay (WTP) for improving groundwater quality through the development of sewerage systems was assessed. The results indicate that there is substantial WTP for water quality improvements. Households are willing to pay 18.25 PLN (4.43 EUR) per month to remain pollution at the maximum safe level according to EU regulations (reducing nitrate concentration in groundwater to 50 $mg \cdot L^{-1}$). Our results add to the expanding literature on the valuation of water resources and can be useful in analysis of investment effectiveness, in the valuation of environmental costs and benefits related to improvement or deterioration of groundwater condition, and in the pricing policy debate in terms of fees and prices for water and water services.

Keywords: groundwater valuation, choice experiment, willingness to pay, groundwater quality

JEL classification: Q51, Q53, Q58