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Fresh- and therapeutic groundwater mixing model in Tylicz region (Polish Carpathians)

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(Received: May 27, 2019; Revised accepted: November 5, 2019)

<https://doi.org/10.18814/epiugs/2019/019024>

The fresh and therapeutic waters near Tylicz have been exploited for nearly 200 years and have come to play a crucial role in the region's economic development. Their chemical composition results from the mixing of (shallow) freshwater with therapeutic water found at depths of 100–200 m. In tectonic environments, both types of water become saturated with carbon dioxide. The overexploitation of either type of water can lead to changes in the way the water mixes and result in the alteration of its physical and chemical properties. The paper presents hydrodynamic model of water mixing drained by wells, basing on the composition and discharge of the waters. The model comprises seven layers to a depth of 900 m and accurately reflects the complex structure of the flysch facies. The well P-1 catchment was subjected to detailed analysis: here the changes in mineralization triggered by altered water are most visible and well-documented. Contrary to initial claims, the results seem to indicate that the exploitation of adjacent freshwater and therapeutic wells does not necessarily have any impact on the waters' chemical composition. It has, however, been proved that the composition of therapeutic water is strongly influenced by therapeutic water discharge.

Introduction

Understanding processes of interaction between therapeutic (therapeutic water was named mineral water with healing properties) and fresh groundwater in aquifer is very important because it can affect the strategy of extraction and protection of water resources against over-exploitation. This problem concerns, among others the Poprad Valley (southern Poland, the Carpathians), where over the past 200 years several local health and bottling industry hubs have evolved (Hacquets, 1796; Zejszner, 1836), in towns such as Muszyna, Krynica Zdrój and Tylicz (Fig. 1). The entire Polish section of the Poprad Valley is referred to as a the 'mineral water bottling basin' (Rajchel, 2012), since it is home to approximately 14 bottling stations and 6 health resorts, which make use of catchments with a joint yield of 220

m³/h (Felter et al., 2015). On the hydrogeological map of Poland, this area has been designated as a separate entity (Dowgiałło and Paczyński, 2002), whose distinguishing feature is the presence of specific therapeutic waters known as acidulous waters (containing no less than 1,000 mg/dm³ of free CO₂) and waters whose CO₂ content falls between 250 – 1,000 mg/dm³ (Buczyński et al., 2017). Owing to their specific properties and the rarity with which they occur, therapeutic waters are under strict protection (Ciężkowski et al., 2010) and their exploitation is regulated by law. This entails classifying therapeutic, thermal and brine waters as mineral resources and defining extraction areas for each of them. The protection of these resources is implemented through avoiding the exploitation of freshwater in areas where it occurs alongside therapeutic waters (Ciężkowski, 2007). Isotope research indicates that the carbonated water or CO₂ rich water found in the Carpathians date back to the Holocene and glacial periods, and as a result of mixing processes comprise a mix of dehydration waters and contemporary infiltration waters (Rajchel, 2012). It also appears that the aquifer system is highly sensitive to changes in the exploitation levels and recharge conditions (Nowicki and Felter, 2013). In particular, these changes will affect the waters' mixing ratio and as such disrupt the chemical composition and dynamics of groundwater reserves. In the area under study, the bottling industry relies partly on fresh water, which is why research into the effects of its exploitation on therapeutic waters is so essential.

Sources assume varying standpoints regarding the contribution of freshwater exploitation to the disruption of the mixing ratio between fresh and therapeutic waters. Studies have shown that therapeutic waters occurring naturally in south-western Poland (e.g., in Łądek Zdrój) exhibit notable variations in discharge following the establishment of new wells (Ciężkowski, 2007). In the Carpathians, variations in the concentration of carbon dioxide and the decline in mineralization of acidulous waters have been associated mainly with earth moving and mining activities or malfunctions in the water supply system around the towns of Piwniczna, Krynica Zdrój and Szczawnica (Rajchel, 2012). In a small number of wells near Tylicz, mineralization levels exhibit considerable multi-annual variation, which cannot always be attributed to exploitation, although in some cases there appears to be a clear connection. Despite these inconsistencies, the exploitation of new freshwater catchments in areas where therapeutic waters occur is prohibited.

The regional groundwater model created for the purposes of this research covers 70.4 km² and includes the drainage basin of the upper

Figure 1. Study area.

river Muszynka (53.2 km²) and was intended to illustrate the way fresh and therapeutic waters mix, and to enable the assessment of the way their catchments influence each other. It also served to evaluate therapeutic water reserves and to determine whether adjacent therapeutic and fresh water catchments can be safely exploited. The advantage of suggested method (in comparison to chemical and isotopic analysis) is possibility to generate prognoses, which show the steady-state (final) composition of water by known discharge. Also the effects of the increased therapeutic water exploitation on the mixing ratio between these and fresh waters were studied, and the results of model research were compared with results obtained using the Ovczynnikov method. Due to the volume limited of the paper, detailed test results based on

the one year H, O, and S isotope and chemical observations (hydro-geochemical mixing model) described in Buczyński et al., (2015), Staško and Modelska (2016).

Research Area

Location and Climate

Hydrogeological model was constructed to simulate Muszynka river drainage basin to the hydrological profile in Powroźnik (area of 53.2 km²), located in South Poland (Fig. 1), in Outer Western Car-

pathians. Owing to its river network and the specific drainage pattern, the region exhibits significant morphological variation (509 – 894 m above sea level). The average annual temperature ranges from 4 to 6 °C. Average year-long precipitation levels fall between 849 mm at the station in Krynica Zdrój (Institute of Meteorology and Water Management) and 862 mm at the station in Tylicz (Multivita database). In the drainage basin of the upper river Muszynka, seven wells are used to extract fresh water, while the exploitation of therapeutic water is restricted to only three such sites. The total available resources of therapeutic water are 12.4 m³/h. For fresh water this value is several times higher.

Geology and Hydrogeology

The research area is a part of Carpathy Mts (Polish outer Carpathian), composed of flysch (sandy-clayey layered sediments) – product of deep sea sedimentation, which is divided into units, depending of tectonic, faults and facial diversity. The area, where the model is constructed, can be divided in two main tecto-facial units: Bystrzyca unit and Krynica unit. The mentioned main units are divided into several formations, separated by sedimentary or tectonic barriers. The geological profile consist of sediments from the middle to late Eocene epoch. The Bystrzyca unit includes mainly shales and next – sandstones, and occasionally – marbles. In this unit Beloveza Formation and shales of Magurska Formation can be distinguished. The Krynica unit is dominated by sandstone and includes such formation as: Zarzecze Fm, Piwniczna Fm, Szczawnica Fm and Magura Fm. Two main tectonic zones extend over this area: Tylicz fault and Krynica fault. The morphology and surface water are strictly connected with main direction of this deformation (NE–SW and NW–SE). Numerous dislocation and fractures gives a preferential condition for CO₂ migration from deeper part of lithosphere (Birkenmajer, 1986; Birkenmajer and Dudziak, 1988; Birkenmajer and Oszczypko, 1989; Oszczypko, 1991, 1998; Oszczypko et al., 1999).

According to the regionalization of fresh water by Paczyński (1995), the research area is part of the Carpathian hydrogeological region, where groundwater resources can be found mostly in flysch formations and less - in quaternary sediments of valleys. The thickness of quaternary deposits of the Muszynka's drainage basin is limited to 15 m and creates a local source of groundwater (Szczepański and Szklarczyk, 2005). More perspective resources occur within Neogene flysch. Flysch rocks do not exhibit typical aquifer formations; the presence of water resources is associated with sub-surface fissures and weathered rocks (often of varying ages). As previous research shows, the lowest border of circulation and fresh groundwater exchange reaches depths of 60–80 m, depending on the rock type and morphology (Chowaniec, 2006), or up to 100 m (Witczak et al., 2002). The amount of water retained in the flysch rocks is determined by the shape and porosity of sandstone units. More water-bearing are coarse-grain sandstones than mudstones and sandstones with mud cement. Extensive studies have shown that the effective porosity of sandstones from Bystrzycka unit and Krynicka subunit is low (1–10%), while the storage coefficient fluctuates between 1.06×10^{-4} – 1.06×10^{-5} (Krawczyk, 2010a, b). Tectonic and weathering processes result in development of cracks and fissures, building secondary porosity and permeability. Despite the rate of water exchange decrease with depth, the pressure distribution is under influence of morphology even up to depth of 1,500 m (Witczak

et al., 2002; Zuber and Chowaniec, 2009). The hydraulic conductivity from pumping tests of the fractured- porous medium varies between 1.13×10^{-4} and 1.25×10^{-9} m/s (Nałęcki et al., 2004). Jetel (1986), after analyzing the results of pumping tests, proposed the formula describing the relationship between the hydraulic conductivity and depth:

$$K_H = K_0 e^{-aH} \quad (1)$$

where K_H – hydraulic conductivity at the depth of H [m/s];

K_0 – hydraulic conductivity of the near the surface sediments [m/s];

a – empirical coefficient

Genesis and Occurrence of Therapeutic Waters

Carbon dioxide-containing waters as well as acidulous waters occurring in the area under study are either contemporary or glacial, and diagenetic in origin. They are found predominantly in river valleys. The genesis of the endogenous carbon dioxide current remains a point of contention, although the theory suggesting the involvement of a number of different sources and processes (igneous, metamorphic and diagenetic) is nowadays the most widely accepted. Rajchel (2012) recapitulates these theories and concludes that the carbon dioxide originates in the subduction zone. In the area under study, many dry CO₂ exhalations have been observed, apparently unrelated to therapeutic water reserves.

Based on the hydrogeological model created for the purposes of evaluating therapeutic water reserves, Kania et al. (2009) draw the conclusion that deep circulation within the regional flow system is essential for the creation of therapeutic mineral water, while waters taking part in the regional flow system (between 100m and 200 m below ground level) may be identified with disposable resources of therapeutic water. Therefore, acidulous waters do not necessarily have to be old, since both contemporary infiltration waters and their blend with deep circulation waters can become saturated with CO₂. This is shown in Fig. 2 (Rajchel 2012).

Figure 2. Model depicting the forming of carbon dioxide-rich waters in the Poprad Valley.

Figure 3. Location of well P-1.

For therapeutic waters, a safe yield was determined following the analyzes of CO₂ exhalations, CO₂ content in soil air and the occurrence of acidulous water springs, as well as the presence of well bores in which therapeutic waters were observed; it was found to cover 7.47 km². This area of coexistence of fresh and therapeutic waters was first mapped out (Fig. 3) in 1996 (Poprawski et al., 1997) and modified in 2006 (Staško et al., 2007).

Methods

Hydrogeological Model Construction

Hydrogeological model was constructed for steady-state conditions. The model was developed in Visual Modflow software, a well-verified tool, used for water balance studies (McDonald and Harbaugh,

1988). There was applied a discretization grid by dividing model area into 194 rows and 148 columns. Grid spacing was denser (50 m) in the region of wells locations and increases to 100 m in peripheral zones. The upper boundaries were established along the terrain surface.

There was constructed 7 numerical layers – each of constant thickness, in range 30–400 m, which reflected decreasing of hydraulic conductivity in flysh formation. The model bottom was applied 900 m b.t.s., to include the deepest groundwater intakes in model surrounding. The remaining boundaries were moved slightly beyond the border of the drainage basin in order to include all well influences. General-head boundary (GHB) was established for these borders. The recharge was set using a constant flux boundary condition, while the third-type reflected rivers and springs (Fig. 3).

The calibration process was conducted by trial-and-error method and was described in detail by Buczyński and Wcisło (2013). As a target for water tables, springs elevation was used as well as unused wells

Figure 4. Observed vs. calculated hydraulic heads.

and calibration met the stated criteria (Fig. 4). Also for water budget, river fluxes corresponds in model and from field data (discrepancy <5%). As an outcome, the hydraulic conductivity distribution was obtained (Buczyński and Weislo, 2013) as well as water table distribution (Fig. 5) and water budget (Table 1).

Simulation of Mixing Processes

According to previous research (Genesis and Occurrence of Therapeutic Waters), budget area for therapeutic water was applied to the model by creating zone budget in a 3rd layer (Fig. 6). The fluxes from the 4th (old, deep water circulation) plus from sides (relatively young water from infiltration) can be treated as therapeutic water resources (as a mixing result).

In such scheme also can be investigated mixing process under influence of changing of therapeutic and fresh water abstraction. In

the designated area, characterized by the coexistence of fresh and therapeutic waters, researchers carried out a local assessment of groundwater resources. Wellbore P-1, whose average daily yield in 2016 equalled $Q=9.9 \text{ m}^3$, was chosen for this purpose, seeing as it demonstrated variations in mineralization in response to changes in withdrawal. The results were calculated in accordance with the created model. The area subject to the balancing lies in the rock mass at the depth of the bore, 100–200 m below ground level (Fig. 6).

Inflow from above and from the sides was identified as fresh water, while recharge from below (the fourth level of the model) was regarded as therapeutic water. Following the same methodology, an experiment was conducted in which a fictional freshwater well (F) was placed at a distance of approximately 250 m from well P-1 (a therapeutic water catchment). The effects of variations in the yield of well F on the mixing ratio of the waters drawn in the P-1 wellbore were subsequently tested. Finally, the impact of changes in the exploitation of well P-1 on the waters' mixing ratio was also evaluated.

Waters Mixing in Light of Correlation HCO_3 and Conductivity

The mixing process involving deep waters (typically thermal, mineral or rich in carbon dioxide) can be studied using various methods which rely primarily on isotope analysis or chemical composition (Cartwright et al., 2002; Balderer et al., 2014), as well as hydrochemical modelling.

One of these methods involves analyzing general mineralization and the content of a correlated component in the water (Ovczynnikov, 1963). In the case of mineral waters occurring in the Tylicz region, the component demonstrating significant correlation is the bicarbonate ion (Fig. 7). Since the electrical conductivity of water is the most frequently tested parameter, the graph below illustrates its correlation with the HCO_3^- ion content. Additionally, Table 2 presents variability statistic of conductivity.

Maximal noticed conductance ($\text{cond}=3,100 \text{ mS/cm}$) was interpreted as 100% participation of therapeutic water. 100% of fresh water corresponds to $\text{cond}=448 \text{ mS/cm}$ (average for fresh water from wells and springs in analyzed area).

Table 1. Water budget of modeled catchment in Tylicz region ($F=53.2 \text{ km}^2$)

IN	[m^3/d]	%	OUT	[m^3/d]	%
Recharge	27 781.0	95.0	River drainage	27 961.0	95.6
River infiltration	398.3	1.4	Springs drainage	634.7	2.2
Inside	1 069.3	3.7	Outside	650.8	2.2
Total	29 248.6	100.0	Total	29 246.6	100.0
Discrepancy	2.1	0.0

Figure 5. Water table contour map (model result, 2nd layer).

Figure 6. Cross-section of the balancing region of the P-1 wellbore inflow. The balancing area has been darkened.

Table 2. Conductance variability in therapeutic water wells in Tylicz region in years 2006–2016

Well name	Number of analyzes	Conductance (mS/cm)			Range of variability (mS/cm)
		Min.	Max.	Avg.	
P-2	1031	3.100	1.574	2.183	1.526
P-1	887	1.191	0.590	0.940	0.601
P-3	906	1.448	0.653	0.971	0.795
mean	941	1.913	0.939	1.365	0.974

Figure 7. HCO_3^- ion content vs conductivity (therapeutic water from Tylicz region).

Results

The goals of the modeling were to investigate i) therapeutic water resources in the model by expressing mixing process of entire model, ii) mixing process in local scale by balancing water fluxes to the capture zone and influencing of fresh and therapeutic water extracting.

Regional Resources Assessment

For regional (total) therapeutic water resources, the zone budged was used derived from previous research. In next step, fluxes to this zone from sides and from the bottom in 3rd model layer were calculated (100–200 m b.t.s.). Resulting outcome was:

$$Q = 1.162 \text{ m}^3/\text{d}$$

For the area of the 53.2 km², (in this study) was obtained 18.44 m³/(d·km²) or 7 mm/a.

Mixing in Capture Zone

Investigation of ascending and side flow can be applied by water

balance of capture zone for well P-1 (therapeutic water, $Q=9.9 \text{ m}^3/\text{d}$ in 2016 and $55 \text{ m}^3/\text{d}$ in 2006- the highest) in the model. Such balance equation was shown below on the graph (Fig. 9). Italic marked elements show the water balance for exploitation $Q=55 \text{ m}^3/\text{d}$.

There was applied the approach, where mixing proportion is dependent on ascending part of water in comparison with side water flow into capture zone.

In case of actual discharge ($9.9 \text{ m}^3/\text{d}$) – therapeutic water participation equals $14/(14+47+0)=23\%$, but in case of increased discharge ($55 \text{ m}^3/\text{d}$), participation of therapeutic water is lower: $35/(35+108+66)=17\%$. The differences are apparent. Increase of therapeutic water participation in 2016 is caused by reducing of fresh water inflow (from sides and top). The origin of observed phenomenon it's not only change of water discharge, but changing also the capture zone area for years 2006 and 2016.

In the second stage of investigation, in the capture zone of P-1, the virtual well was placed (F–fresh water only) and the water budget was analyzed once again (Fig. 10). As F–discharge $Q_F=90 \text{ m}^3/\text{d}$ (typical for the research area) was taken and for therapeutic water in P-1 $Q_T=55 \text{ m}^3/\text{d}$ was applied (high value from 2006). Bold marked elements show the water balance for exploitation therapeutic and fresh water simultane-

Figure 8. TDS and discharge graph in well P-1.

Figure 9. Budget of fresh and therapeutic water mixing in catchment area of well P-1 (therapeutic water discharge 10 m³/d and 55 m³/d).

Figure 10. Budget of fresh and therapeutic water mixing in catchment area of well P-1 (therapeutic water discharge 55 m³/d - italic and fresh water 90 m³/d + therapeutic water 55m³/d - bold).

ously, italic - therapeutic water only.

As an outcome, the participation of therapeutic water was obtained: $37/(37+107+66) = 18\%$.

The results are unequivocal – exploitation of fresh water by virtual well doesn't exert any influence on fresh/therapeutic water proportion, the difference in water budget with and without fresh water exploitation is minimal (about 1 m³/d).

Discussion

The outcomes need to be discussed by comparison with another research in different scales and numerical model verification as a main method in this analysis.

Regional Resources Assessment of Therapeutic Water

Therapeutic water occurrence in Polish catchment of Poprad river (Carpathians) was defined basing on it's direct observation (wells, springs) and CO₂ content in soil. The therapeutic water resources were assessed by water budget analyzing on numerical model on the depth of 70–170 m b.t.s., by comparison of ascending- and side flows in the region of therapeutic water occurrence.

By analyzed catchment area of 483 km², the therapeutic water was recognized on the 105.16 km². The resources were estimated to 19,442.4 m³/d (Koślacz et al., 2014). In this research area (53.2 km²), the therapeutic water occurs on the 7.47 km² (Fig. 3) and resources equal to 1,162 m³/d (the modular value 0.25 dm³/s·km²).

The modulus obtained in present study is lower than by Poprawski et al. (1997), Ciężkowski et al. (1999) and Koślacz et al. (2014), respectively: 0.33, 0.37 and 0.64 dm³/s·km².

In every case, comparison of water resources with allowed exploitation suggest there are significant reserve.

Mixing of Therapeutic and Fresh Water in the Poprad Valley

Water exploited by well P-1 shows cond=1.04 mS/cm (a 2016–2017) and is characterized by fluctuations and increase from 2006. The inverse correlation with mean-year discharge is clear (Fig. 8). Former research shows lower conductance before 2006 (Staško et al., 2007).

In regional investigation (Staško et al., 2007) conducted in years 2004–2007, hydrochemical model was implemented resulted in showing in well P-1 the proportion of therapeutic/fresh water 25%/75%.

Now, using extended analysis, for more wells and longer time (2006–2016), there were obtained a little different outcomes (Fig. 7) in 2016 (cond=1.11 mS/cm), the participation of therapeutic water is 24% and the 10-years mean is 18% (cond=0.94 mS/cm). The model gave also 23% – the result remaining in high accordance, taking into account steady-state conditions. In this light, the results suggest, that conductance and mixing proportion should be stable in longer time if the same processes will influence on it. The final (long term) conductance for the discharge of 10 m³/d can be estimated to be 0.95–1.00 mS/cm.

Total dissolved solids (TDS), same as conductance, as a parameters reflected mixing proportions, are significantly fluctuating in Tyllicz region (Staško et al., 2007). In years 1974–2006, the range of variability was 270–1,442 mg/dm³ (952 in average). Genesis of this changeability is not quite clear and need to be more detailed investigated. Present research seems to clarify some part of this case and gives promising results to build more complex tool.

In another region of Poprad Valley, Ciężkowski (2007) estimate the mixing proportions for CO₂-reach water on the basis HCO₃⁻ content and TDS. High variability for individual wells is noted in ranges 70–0% and 38–17% of fresh water. For this fluctuation seem to be responsible changing in deep waters inflow or not stable contact with fresh water.

Kotowski and Operacz (2017) investigated discharge and chemistry for water in Poprad Valley (“Zubrzyk”). They also noted high variability in TDS in short- and long-time horizon and encounter difficulties with interpretation of this phenomenon.

Isotopic research (Porwiesz et al., 1995) suggest differences in recharge structure in wells from Tyllicz region. It depends on location and discharge. Max content of surface water was estimated to 69%, in 1/3 population of therapeutic water wells there wasn't any water from rivers content.

Mixing Processes in the Light of Selected Research in the World

There are many publications according to processes of water mixing of different genesis and content. Much often it is to be find the information about fact of mixing than the proportion of ingredients (Cartwright et al., 2002, Marques et al., 2001, Choi et al., 2014, Vinograd, 2004). There are many methods engaged, including: isotopic, mixing models, thermodynamic models, ion exchange and reaction paths.

Balderer et al. (2014) investigated 12 thermal spring in Budapest, basing on Cl and ³⁶Cl proportion and obtained various outcome, between 0 and 100%, 22% on average. They also include tritium analysis.

Renac et al. (2009) conducted research chemical composition of water from different depth in Central Massive (France), during boring 3 new wells (up to 500 m b.t.s.). The interpretation was conducted on mixing and thermodynamic model. Waters taken on 40–60 m b.t.s. included waters from 22 m b.t.s. (60–70%) and deep – from 198 m b.t.s. (30–40%). Water on the depth of 228 and 300 m, included respectively: 16% and 23% “deep” waters (from referential 198 m depth). Analyzed water was characterized by temperatures between 15 and 26 °C. In France also Négrel et al. (1997) estimated participation of mineralized water in geothermal springs and streams on the basis of strontium isotopes proportion. The outcome was 10–30%. While Haklıdır (2013) applying method based on heat and silica solubility in geothermal reservoirs to mixing model, concluded that thermal deep-water in the South Marmara region (Turkey) derive in 70–80% from shallow, cold water.

The above research do not reflect time-dependent variability of the water proportions and bases on averaged values of isotopes or chemical components. In the light of mentioned research, present analysis indicates relatively simple – dynamic mixing model, correctly corresponding with another outcomes. It needs to be highlighted, that authors intention was to investigate exploitation influence on mixing process, which is clear on such model. The advantage of suggested method (in comparison to chemical and isotopic analysis) is possibility to generate prognosis, which show the steady-state (final) composition of water by known discharge. Steady-state hydrodynamical model allows also to face problems with high variability of chemical composition of water resulting from HCO₃ content and TDS – the most important parameters of mineralized, drinking water.

Conclusions

There are many methods that offer an assessment of the proportion of water mixing. Most of them (e.g., hydrochemical and thermodynamic mixing models, chemical balance analyzes, isotopic analyzes) focus on the elaboration of genesis, the age of water and the sources of recharge. It is rarely possible to trace the variability of the mixing proportions of the therapeutic water components and forecast them. In

the light of chemical and isotopic analysis, it is also more difficult to determine the impact of exploitation on the resources of therapeutic waters.

In such cases, in order to study the contribution of the mixing components of the water entering the P-1 well, additional results were provided by the groundwater mixing model (Modflow). It turned out that the increase in the level of therapeutic water exploitation from 9.9 to 55.5 m³/d contributes to the decrease in the participation of the deep component (from 27 to 17%).

The model showed that the presence of a well capturing fresh water (fictitious well F) in the capture zone for the therapeutic water intake (P-1) does not affect the proportions of waters flowing into the well P-1. The test carried out with the F well capacity of 90 m³/d showed only a 1% increase in the participation of therapeutic waters in the well P-1.

The result obtained indicates that the exploitation of fresh water does not have to be forbidden in all areas of co-occurrence of therapeutic and fresh waters. In those areas, where no negative impact of freshwater exploitation on the parameters (quality and resources) of therapeutic waters has so far been found, with the objective of rational management of available water resources and in particular the protection of therapeutic waters, fresh water exploitation could be conditionally allowed. Such exploitation should be carried out "carefully", and the owner should be imposed restrictions and the obligation of continuous monitoring of characteristic components of therapeutic waters exploited both wells and natural springs. In the light of modeling results, such activities seem to be safe, but it should be remembered that none of the models reflects all processes that may be responsible for mixing water, such as changes in the flow paths pattern.

The research results suggest controlling up-to-date graph freshwater discharge vs therapeutic water parameters (e.g., TDS or HCO₃ content). In the first stage (first week of exploitation) - every day, then every week (7–60 day of exploitation), then every month (60–365), then every year. If any negative correlation is observed, the test need to be stopped and fresh water well should be disabled. Adequate method should be practiced for exploitation therapeutic water – in this case controlling therapeutic water components vs discharge. If any correlation exists – it is rational to hold discharge on relatively stable level.

Acknowledgements

The authors are truly thankful Mr. Tomasz Materko for his valuable substantive remarks and constructive help in data collecting Mr. Adam Zwolenik and Paweł Lupa. This research was founded by University of Wrocław. Additionally, authors like to thank the reviewers and co-editor for their detailed comments, which were invaluable in the editing process. Suggestions made by the reviewers were very helpful in the process of eliminating errors and imperfections in the first version.

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