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# GROUNDWATER CHEMISTRY IN THE AREA OF BEŁCHATÓW COAL MINE AFTER 20 YEARS OF OPENCAST EXPLOITATION OF THE SZCZERCÓW FIELD AND THE 45 YEARS LONG PROCESS OF THE "BEŁCHATÓW" LIGNITE DEPOSIT DEWATERING

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**Abstract:** The Bełchatów lignite deposit is located in the central part of a tectonic unit with latitudinal course called the Kleszczów Trench (Baraniecka et al. 1980; Kosowski 1974; Krzyszkowski 1986). The exploitation of the lignite deposit takes place in two fields: the Bełchatów Field and the Szczerców Field. Between the mining fields there is an uplift of Zechstein salt – the Dębina salt dome. After 20 years of operation, low dynamics of changes in the characteristics of chemical quality of water pumped by the Szczerców Field drainage system is observed. Long-term and systematic monitoring of water quality leads to the conclusion that waters from the Szczerców Field drainage are characterized by long lasting stability of Na-Cl ion concentration. The analysis of hydrogeological conditions of the area of interest and the chemistry of waters from the dewatering of the Szczerców Field in 2020 was carried out using the Unified Geological Database (Jednolita Baza Danych Gelogicznych JBDG) of the Bełchatów lignite deposit, in which information on the deposit, results of research and analysis are collected. The article attempts to analyse the chemistry of the groundwater in the Szczerców Field area covered by the exploitation of the lignite deposit, in the time period specified in the title.

***Keywords*: *hydrogeological conditions, groundwater chemistry, deposit dewatering, geological database, hydrogeological borehole, data transfer***

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## 1. INTRODUCTION

The Bełchatów lignite deposit is located in the central part of a tectonic unit with latitudinal course called the Kleszczów Trench. The Kleszczów tectonic trench was formed in the Paleogene, in Mesozoic formations tectonically disturbed in the form of anticlines and synclines, cut by faults. The dominant structural element of the Kleszczów Trench is the southern fault. The upper edge of this fault in the western region of the deposit lies at a depth of 80–120 m, and in the rest of the deposit at a depth of 110–160 m. The northern fault of the Kleszczów Trench is less sharp and its upper edge in the Szczerców Field occurs at depths of 100–130 m. Along the northern boundary of the deposit in the Bełchatów Field, the northern erosion trench has a tectonic foundation. The depth of the trench is comparable to the depth of coal (Motyka et al. 2007). The main faults of the tectonic trench (northern and southern) are accompanied by a number of minor faults. In the Bełchatów lignite deposit, the main coal seam occurs at an average depth of about 130 meters.

The Bełchatów mine is located in the southern part of the Łódź Voivodeship, in the Bełchatów district of the Kleszczów municipality. The lignite deposit is mined using the opencast method in two fields: the Bełchatów Field and the Szczerców Field. Between the mining fields there is an uplift of Zechstein salt – the Dębina salt dome. The dome is uplifted by about 350–450 m in relation to the bottom of the Kleszczów Trench and by about 60–100 m comparing to the banks of the trench. The salt table was drilled at a depth of 170 m, i.e., at an ordinate of +28 m above sea level. Dewatering of the deposit, which is necessary in order to conduct exploitation of minerals, has been carried out with the use of wells system since October 1975 in the Bełchatów Field, and since September 2000 in the Szczerców Field. The pit dewatering system consists of well barriers: external, internal permanent, internal overburden, as well as an auxiliary dewatering system and wells for dewatering of the deepest parts of the pit drilled at working levels. There was a necessity to protect the structure of the salt dome due to the fact that it was in the path of the forced flow of groundwater by the deep dewatering system launched at the Bełchatów Field. In order to reduce the hydraulic gradient in the area of the salt dome, an annular well barrier was used. The barrier was built in 1990–1992 and rebuilt in 2003. In order to ensure the safety of mining operations in the pits, constant inflow of water from outside the pits is being taken over as well as the water table at the ordinates below the permanent shelves and the planned exploitation are being kept (Michalski 1984; PGE GIEK S.A., n.d.).

This article aims to analyse the chemistry of groundwater in the Szczerców Field area covered by lignite deposit exploitation, in the time period specified in the title.

## 2. MATERIALS AND METHODS

### 2.1. DATA SOURCE AND SELECTION CRITERIA

The analysis of hydrogeological conditions of the area of interest and the chemistry of water from the drainage of the Szczerców Field in 2020 was carried out using the Unified Geological Database (JBDG) of the Bełchatów lignite deposit. In JBDG database information on the deposit, results of research and analysis are collected. In addition, literature surveys and the experience of staff conducting exploitation of the deposit and taking part in the short- and long-term planning and design of mining works were used.

The JBDG, which consists of data sets and application software, was developed specifically for the geological and mining works carried out at the Bełchatów Lignite Mine in 1975. It is a dynamic database, systematically updated, verified and upgraded by the Mine and in cooperation with "Poltegor-Instytut". Updating and verification of the database collection have been carried out since 1975. Information obtained during the period of deposit reconnaissance, before the start of mine operation, has also been entered into the database. Data obtained from boreholes, measurements, observations and surveys are collected in dozens of datasets. The information stored in JBDG is entered into the database according to strictly defined rules (Blajda et al. 1995; Czarnecki et al. 1992; Frankowski et al. 2000; Frankowski et al. 2016; Symposium Material, n.d.).

For the purpose of this analysis, the most relevant JBDG datasets are these containing hydrogeological data such as water table position measurements, water chemical analysis results, and the status of wells and piezometers. The set with water table position measurements is the first established datasets in the database. It includes information on water table depths both since the start of mine dewatering, and earlier, from its reconnaissance.

Assessment of the state of the mine dewatering is made on the basis of the results of measurements of the position of the water table in observation holes, which constitute a system for monitoring of the dewatering progress and the degree of lowering of the water table or the pressure of sub-seam water. Measurements in observation boreholes in the excavation and its surroundings are carried out mainly on a monthly basis (Martyniak et al. 2015).

For the purpose of the article, an analysis of the results of tests of water samples pumped by the Szczerców Field drainage system was carried out, mainly in terms of chemical parameters and their changes in a 20 years' time interval. The selection of data for analysis was made from the JBDG database according to the following criteria: the area/contour of selection, the type of boreholes and aquifer complexes from which samples were taken for testing, types of chemical parameters tested, and time intervals. The analysis included the determination of the hydrochemical background, i.e. the recognition of chemical parameters of waters until September 2000 (the start of pumping at the Szczerców Field) and the recognition of water chemistry until 2020 (Jończyk et al. 2018; Kosowski 1974; Martyniak et al. 2023).

### 2.2. EVALUATION OF HYDROGEOLOGICAL CONDITIONS

Hydrogeological conditions in the area of the Bełchatów lignite deposit are diverse and complicated. The main elements shaping the hydraulic contacts are: tectonics of the Mesozoic bed along with widely developed karst phenomena (mainly within the Upper Jurassic formations) and the occurrence of erosion chutes, usually filled with sand and gravel formations (Jończyk et al. 2005; Kuszneruk and Wojtkowiak 2000; Martyniak et al. 2005; PGE GIEK SA, n.d.; Pazdro 1990).

Under natural conditions, the depth of the groundwater table ranged from 1 to 5 meters below the land surface. The water table of the Mesozoic and Paleogene complex was at the level close to the water level in Quaternary sediments. The recharge took place by seepage from higher levels, through hydrogeological windows or on outcrops of Mesozoic rocks. The main recharge zones were the watershed areas of the Widawka River basin and its valley. Before the initiation of deep drainage, groundwater flow was generally from the southeast to the west and northwest. Under the conditions of long-term drainage, the natural circulation pattern changed significantly. The main drainage base has become the excavation area, where groundwater flows have diverted, changing the original natural direction of groundwater flow (Martyniak et al. 2009; Sołtyk et al. 2007; Sołtyk et al. 1996).

In the pit and its surroundings, three aquifer complexes can be distinguished: the Quaternary-Neogene, Paleogene and Mesozoic (Cretaceous-Jurassic), remaining in differentiated, sometimes limited hydraulic contacts with each other.

### 2.3. DETERMINATION OF THE HYDROCHEMICAL BACKGROUND OF GROUNDWATER IN THE SZCZERCÓW FIELD

The activation of the deep dewatering system of the Szczerców Field took place in September 2000 in hydrodynamic conditions shaped by the long-standing dewatering of the Bełchatów Field and the Dębina salt dome. The opening located in the western part of the Szczerców Field was within the range of influence of the dewatering of the Bełchatów Field, with a lowering of the original groundwater table in the depth range of 20–30 m below the ground level (Paszkiewicz 2001; Siciński and Kuszneruk 1997; Sołtyk et al. 2007; Sołtyk et al. 2009).

The location of the opening of the Szczerców Field in relation to the excavation of the Bełchatów Field and the wells of the protective barrier of the Dębina salt dome is shown in Fig. 1.

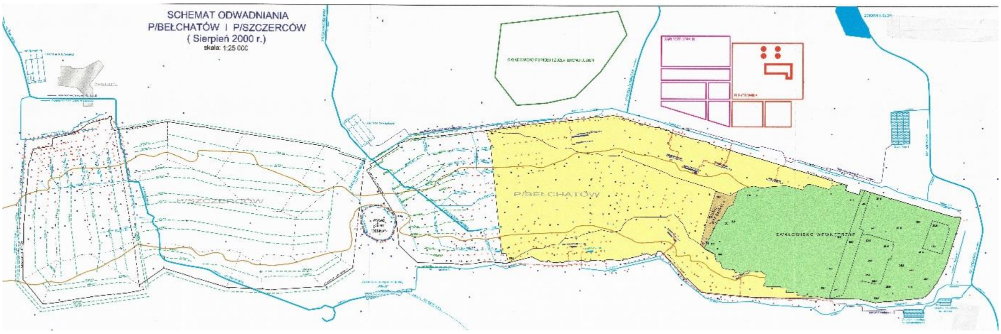


Fig. 1. Diagram of the drainage of the Belchatów Field and the Szczerców Field at the stage of establishing the hydrochemical background (Paszkiewicz 2001)

Before starting the operation of the deep dewatering system in the Szczerców Field, the initial state of groundwater chemistry was established. Examination of water quality and assessment of the range of concentrations of particular indicators with subsequent systematic monitoring of pumped waters gives an opportunity to identify quickly changes in the water chemistry occurring under the influence of increasing depression within the excavation. This is because the upper limit of the natural hydrogeochemical background is the level whose exceedance indicates anomalous concentrations caused by mining activities (Sołtyk et al. 2000).

The hydrochemical background level was determined based on a set of data obtained from chemical analyses of water taken from existing hydrogeological boreholes – wells and piezometers capturing defined aquifer complexes. The wells and observation wells located in the area of the planned mine opening and in the area between the planned opening and the Dębina salt dome were tested. During the preparatory work phase, more than 400 analyses of groundwater samples were carried out in several stages of work prior to the start of the deep dewatering system (Table 1). The distribution of sampling in each aquifer complex is shown in Fig. 2.

Table 1. Number of samplings in particular aquifer complexes before starting of drainage system

| | Mesozoic | Cenozoic | Paleogene | Total | Testing stage |
|---|---|---|---|---|---|
| Wells | 82 | 30 | – | 112 | assessment of the technical condition of holes |
| Piezometers | 25 | 47 | – | 72 | made before 1999 |
| Piezometers | 54 | 56 | 20 | 130 | assessment of the technical condition of holes in 1999–2000 |
| Piezometers | 20 | 24 | 10 | 54 | sampling within the hydrochemical background |
| Wells | 34 | – | – | 34 | team pumping |
| Total | 215 | 157 | 30 | 402 | – |

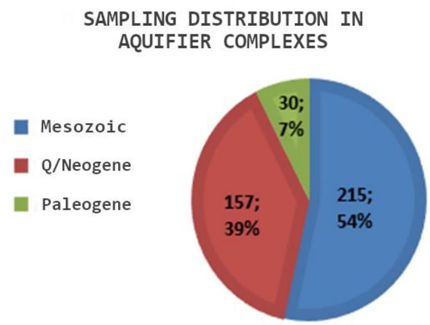


Fig. 2. Distribution of sampling in individual aquifer complexes

When evaluating groundwater quality characteristics in the phase of determining of the hydrochemical background of the Szczerców Field, according to Sołtyk et al. (2000), it should be bore in mind that the natural hydrochemical background of groundwater in the usable aquifers of Poland (according to the results of determinations made within the framework of the research program of the Main Groundwater Reservoirs) is:

a) bicarbonates 60–360 mg/dm$^3$,
b) chlorides 2–60 mg/dm$^3$, anomalies >100 mg Cl/dm$^3$,
c) sulfates 5–60 mg/dm$^3$, anomalies >100 mg $SO_4$/dm$^3$.

Taking the given values as a criterion for assessing the content of main anions in groundwater, it can be concluded that in the area of the opening and between the opening and the salt dome Dębina:

a) no water with anomalous bicarbonate ion content was identified,
b) incidental increased concentrations of sulfate ion – above 100 mg/dm$^3$ were found in all mosaic water-bearing complexes of mostly anthropogenic origin,
c) water containing chloride ion above 100 mg/dm$^3$ was found only in sub-bed sediments, which was identified as a chloride anomaly in Mesozoic sediments in the eastern part of the opening.

A synthesis of the statistical assessment of the concentration of the main components of the waters of the above-deposit and sub-deposit horizons, along with the established type of mineralization according to the Shukariev–Priklonskii classification, is presented in Table 2 based on the analysis according to Sołtyk et al. (2000).

The initial groundwater chemistry of the Quaternary-Neogene complex in the Szczerców Field is of the bicarbonate-calcium type, containing on average no more than 20 mg/l of chlorides and up to 300 mg/dm$^3$ of dissolved substances.

The entire groundwater within the sub-bed aquifers (Paleogene, Mesozoic) has a slightly different $HCO_3$-Cl-Ca-Na water type (Table 2) compared to the horizons lying more shallowly. A higher concentration of Na-Cl ions is evident, indicating a dependence of the concentration of these ions as a function of sampling depth. This is consistent with the natural hydrogeochemical gradient, which in the Mesozoic waters of the Polish Lowlands is about 75 mg/dm$^3$ per 100 m depth (Sołtyk et al. 2000). The numerical values of hydrochemical indicators, calculated based on the results of the determination of macro- and microelements in groundwater, prove the contact with fresh near-surface waters and the recharge of all studied stratigraphic levels by precipitation. This is confirmed by the sodium-chloride index of about 1, calcium-strontium index of about 313 and chloride-bromide index >500 (Sołtyk et al. 2000).

Table 2. Hydrochemical background – average concentration of major ions

| | Unit | Cations | | | Anions | | |
|---|---|---|---|---|---|---|---|
| | | Ca | Mg | Na + K | $HCO_3$ | Cl | $SO_4$ |
| Overburden levels | mg/dm$^3$ | 63.4 | 10.0 | 8.9 | 190.4 | – | 9.8 |
| Equivalant | mval/dm$^3$ | 3.16 | 0.82 | 0.40 | 3.1 | 0.52 | 0.2 |
| Ionic type | **$HCO_3$-Ca** | | | | | | |
| Sub-bed levels | mg/dm$^3$ | 59.2 | 13.0 | 52.8 | 222.5 | 45.8 | 12.6 |
| Equivalant | mval/dm$^3$ | 2.95 | 1.06 | 2.26 | 3.63 | 1.29 | 0.26 |
| Ionic type | **$HCO_3$-Cl-Ca-Na** | | | | | | |

The hydrochemical background of the Szczerców Field in 2000 shows comparable contents of groundwater chemistry indicators to the initial phase of the Bełchatów Field drainage (Table 3). In 1987, i.e., after 12 years of operation of the Bełchatów Field dewatering system, the pumped waters were fresh, di-ionic waters of the $HCO_3$-Ca type, with low mineralization and slightly increased iron content (Martyniak and Ślusarczyk 2009; Wojtkowiak 1987).

Table 3. Average physicochemical parameters of groundwater pumped in 1987 in Bełchatów Field (B/F) (Ślusarczyk 1986) and determined in hydrochemical background phase of Szczerców Field (Sz/F)

| | General mineralization | pH reaction | Temperature | Chlorides | Sulfates | Fe |
|---|---|---|---|---|---|---|
| B/F | 250 | 7.0–7.6 | 13.0–16.0 | 15 | 30 | 0.5–1.0 |
| Sz/F overburden | 257–276 | 7.5–7.7 | 14.0–14.9 | 18.3 | 9.8 | 0.7–0.9 |
| Sz/F sub-bed | 386 | 7.7–7.9 | 14.0–14.5 | 45.8 | 12.6 | 0.5–0.7 |

An area of chloride anomaly was found at the hydrochemical background study stage. Waters pumped by wells located a short distance south of the northern boundary of the deposit – along the eastern edge of the mine opening contained extreme chloride ion content of up to 288 mg/dm$^3$.

All waters tested in the area of the mine opening met the classification criteria for high-quality waters according to the 1993 recommendations of the Polish Environmental Protection Agency (Martyniak et al. 2009).

## 3. RESULTS

After 20 years of operation of the deep dewatering system of the Szczerców Field, the percentage of basic ionic chemical constituents of pumped waters has changed while the mineralization of the waters has remained at the same level. As the groundwater table is lowered, the chemistry of the water changes. It is due to the increased velocity of water flow, the thickness of the aeration zone and the increased inflow of sub-bed waters. Extensive and systematic monitoring of the quality of pumped water and water discharged into surface watercourses makes it possible to analyse the phenomena occurring under the influence of the activities carried out, and also provides an opportunity to determine the early symptoms of processes causing a transformation of the ionic type of water. From the beginning of the dewatering of the Szczerców Field (from IX 2000) until the end of 2020, in following years of monitoring, the range of hydrochemical tests included an average of about 50–76.5% of instantaneous volumes of water pumped by the deep dewatering system. The distribution of well sampling in the particular years of the Szczerców Field dewatering system operation is presented in Fig 3. In connection with the progress of dewatering of the Szczerców Field, the proportions and number of overburden and sub-deposit wells have changed in relation to the initial state. The number of investigated overburden wells is limited. This causes that the average value of the concentration of main ions in the total volume of the investigated wells refers, in general, to waters from the Paleogene and Mesozoic complexes.

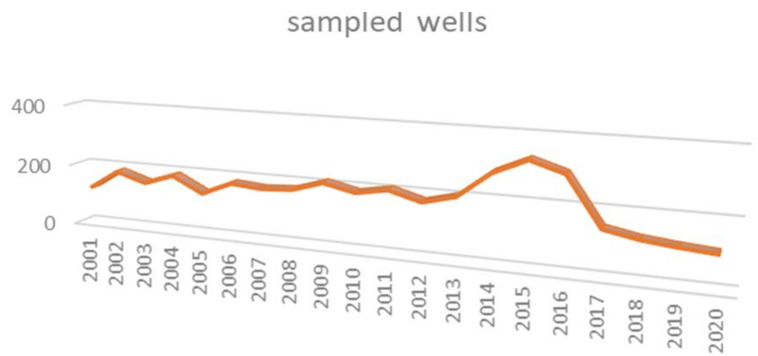


Fig. 3. Number of sampling of working wells over 20 years of operation

In 2020, all tested waters pumped by the dewatering wells were fresh waters with dissolved substances content: *m* = 384.2 ± 137 mg/dm$^3$, average hardness of 5.54 ± 1.87 mval/dm$^3$ with slightly alkaline reaction pH = 7.5 and average temperature of 13.3 ± 0.7°C.

The average concentration of the main water indicators in 2020 is shown in Fig. 4.

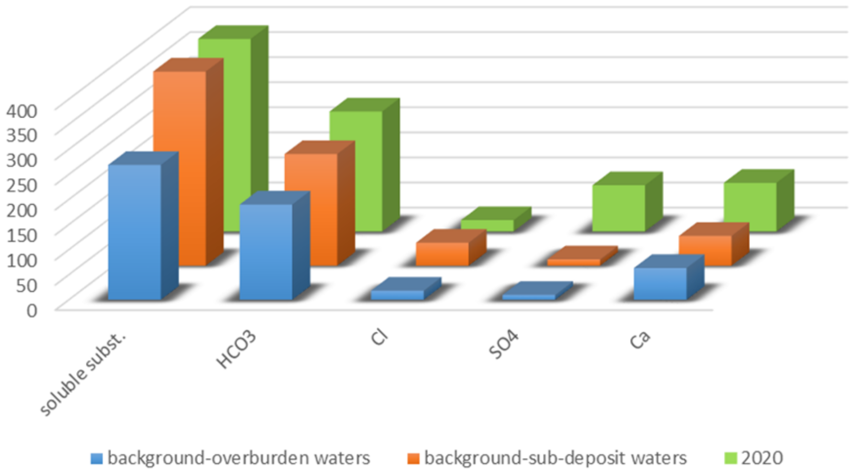


Fig. 4. Average concentration [mg/dm$^3$] of basic ions of water pumped by Szczerców Field wells after 20 years of operation

After 20 years of dewatering system operation, water from the Szczerców Field changed its average ionic composition from the two-ion type $HCO_3$-Ca to the three-ion type $HCO_3$-$SO_4$-Ca. The main influence on the transformation of the composition of pumped waters has increased proportion of sulfate-calcium ions. In the Szczerców Field, the increase of sulfate content is caused by the favorable natural conditions of underground oxidation of sulfide minerals. Analysis of the isotopic composition of sulfates confirm the indicated genesis of sulfate mineralization. In the tested wells, the oxygen isotope has negative values $\delta^{18}O < 0$ [‰ VSMOW], which is characteristic of the geogenic origin of the sulfates. Before starting of dewatering of the Szczerców Field, the concentration of radon activity in the waters of the Paleogene and Mesozoic complex was low, not exceeding CRn222 < 0.2 [Bq/dm$^3$].

The study of the natural content of radon and radium in 2020 indicates an increased concentration of these natural environmental isotopes. This is a symptom of improved diffusion conditions and confirms an increased contribution of vertical inflow of deeper circulating waters. The results of tests performed throughout the groundwater monitoring period shows that the process of sulfate reduction in the waters of the sub-bed levels was faster than in waters in direct contact with infiltration of precipitation (Kosowski 1974)

– decreasing tritium concentrations from 6.8 [TU] to 1.2 [TU]. According to the Regulation of Ministry of Maritime Economy and Inland Navigation (Rozporządzenie MGM i ŻŚ 2019), the concentration of sulfate ions met the requirements specified for groundwater of III quality class, calcium content – the requirements specified for II quality class. Table 4 summarizes data on average indicators in pumped water for the last 5 years comparing to the hydrochemical background.

Table 4. Average composition of water pumped through the Szczerców Field drainage system

| Indicator | Background: overburden waters | Background: sub-deposit waters | 2016 | 2017 | 2018 | 2019 | 2020 |
|---|---|---|---|---|---|---|---|
| pH reaction | 7.68 | 7.78 | 7.42 | 7.54 | 7.52 | – | 7.4 |
| Dissolved subst. | 269 | 387 | 311 | 319 | 336 | 341 | 384 |
| Calcium Ca | 63.4 ± 14.7 | 59.2 ± 18.4 | 83.0 ± 34.5 | 80.1 ± 14.6 | 82.9 ± 26.5 | 83.2 ± 19 | 97.0 ± 35 |
| Sodium + Potassium | 8.9 ± 3.1 | 52.8 ± 39.4 | 16.1 ± 24.8 | 26.1 ± 41.3 | 35.9 ± 47.5 | 36.1 ± 40 | 21.7 ± 17 |
| Bicarbonates | 190.4 ± 63.1 | 222.5 ± 48.9 | 241 ± 46 | 249 ± 31 | 254 ± 119 | 247.7 ± 26 | 239.3 ± 31 |
| Chlorides | 18.3 ± 8.3 | 45.8 ± 27.7 | 16.2 ± 28.9 | 28.3 ± 49.5 | 39.6 ± 54.0 | 38.3 ± 40 | 22.6 ± 20 |
| Sulfates | 9.8 ± 5.5 | 12.6 ± 7.0 | 58.6 ± 88.8 | 41.2 ± 31.1 | 50.0 ± 23.8 | 62.2 ± 37 | 92.2 ± 88 |
| Ion type | $Ca\text{-}HCO_3$ | $Ca\text{-}Na\text{-}HCO_3\text{-}Cl$ | $Ca\text{-}HCO_3\text{-}SO_4$ | $Ca\text{-}Na\text{-}HCO_3$ | $Ca\text{-}HCO_3$ | $Ca\text{-}Na\text{-}HCO_3\text{-}SO_4$ | $Ca\text{-}HCO_3\text{-}SO_4$ |

Above table shows that the water from the Szczerców Field dewatering has maintained over several years a constant composition of major ions within a single standard deviation. This proves the minimal dynamics of changes in the quality of chemical characteristics after 20 years of Szczerców deposit dewatering (Kalbarczyk 2021).

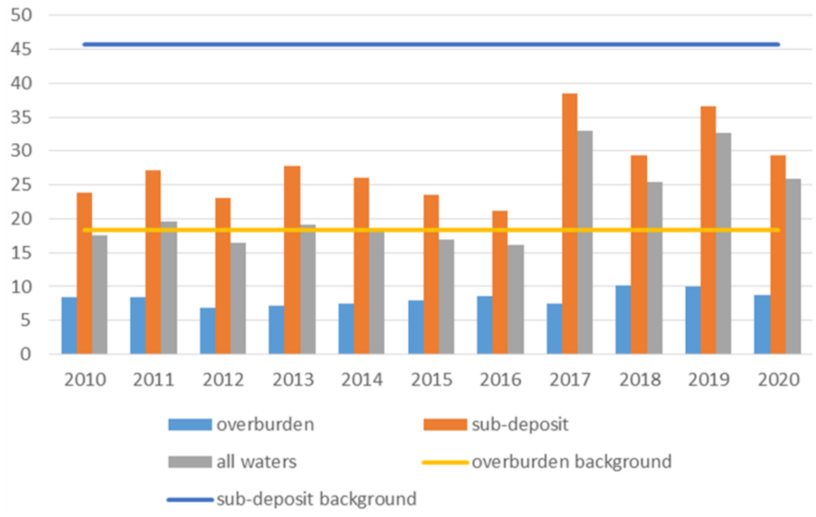


Fig. 5. Average concentration [mg/dm$^3$] of basic ions of water pumped by Szczerców Field wells after 20 years of operation

In 2020, compared to the initial state, there were no statistically significant changes in the content of chloride ions in the waters of the tested wells. It should be emphasized that the average chloride content of pumped waters, defined in 2020, remains below the hydrochemical background level of waters from these aquifers, which in 2000 was deter-mined at 45.8 mg/l for sub-bed horizons and 18.3 mg/l for Quaternary-Neogene aquifer sediments. The graph below shows average chloride concentrations over the decade with a breakdown by overburden and sub-deposit complexes (Fig. 5).

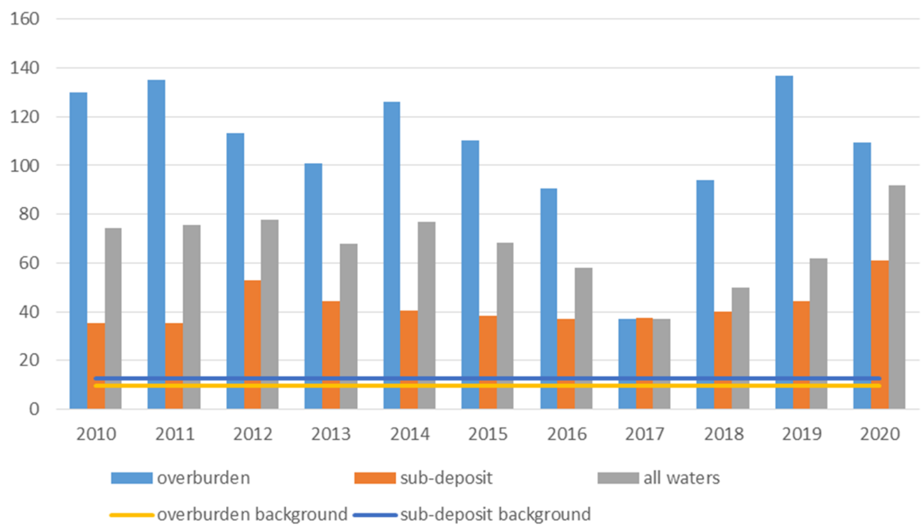

Fig. 6. Average sulfate concentration [mg/dm$^3$] in waters pumped for 10 years

The persistent nature of the positive chloride anomaly established during the hydrochemical background study phase is confirmed throughout the operation period. It occurs in the area defined by the location of barrier wells C, E and PPS drilled in the eastern direction. The concentration of chloride in the pumped waters remains above 100 mg/dm$^3$ without a significant increase trend. Its range remains limited within the sub-bed complexes with the axis moving eastwards in the central part of the deposit. The above thesis is presented in Fig. 7. Area with the anomaly >100 mg/dm$^3$ has been colored.

The chloride anomaly coincides with the thermal anomaly, in which the water temperature is above 15°C. The temperature of pumped water as a function of time and dewatering progress shows no tendency to increase.

Based on the research performed, it can be concluded that the dewatering system of the Szczerców Field is characterized by long-term stability of Na-Cl ions concentration with a local higher concentration in a small area in the western part of the pit (Kalbarczyk 2021).

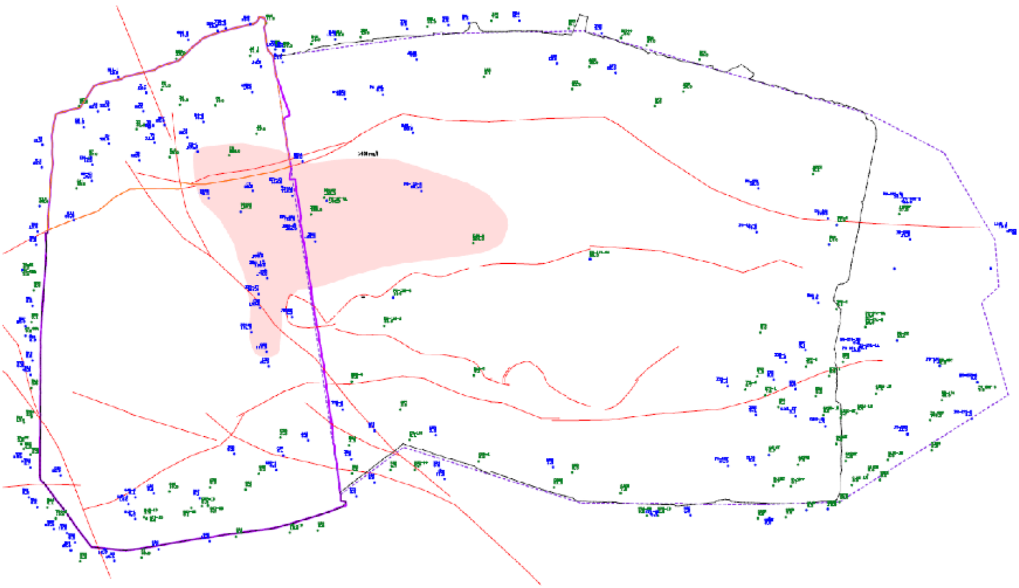

Fig. 7. Chloride anomaly range in the excavation of the Szczerców Field at the state of work in 2020

It is to be noted that in the function of the exploitation time of the dewatering system, the content of sulfates originating from the geogenic oxidation process of sulfide minerals increases. This fact is confirmed by a graph showing the average concentration of sulfates over a period of a decade, divided into overburden and sub-seam wells complexes (Fig. 6).

## 4. DISCUSSION

The state of water chemistry of the Szczerców deposit in the light of the 45 years process of dewatering of the “Bełchatów” deposit. The current process of dewatering of the lignite deposit in the Bełchatów Field, including the second-order trench down to –100 m above sea level, has not caused any radical changes in water quality. The hydrogeochemical transformation observed in the water environment of the Bełchatów Mine area refers mainly to increased proportion of sulfate ions, which have varied origin. The study of the isotopic composition of sulfur and oxygen in the sulfate ion makes it possible to determine the source of the increased sulfate concentrations. Positive isotope values indicate hydrochemical phenomena associated with the storage of ash in the Bagno Lubień landfill (the wells of the northern barriers of the Bełchatów Field), negative isotope values reflect physical and chemical processes in various phases of controlled restoration of the groundwater table (the eastern part of the Bełchatów Field, where the internal dump of overburden and ash is being formed). During the 45 years of dewatering process, the content of sulfate in the pumped waters is more than 6 times higher than the natural initial concentration assumed at 31.8 mg $SO_4/dm^3$. A much lower growth rate is for chloride ions, whose average concentration in pumped water exceeds the background value of 15.3 mg $Cl/dm^3$ by more than 2 times. The mineralization of water increased by 150% when changing its type from the two-ion $HCO_3$-Ca to the three-ion type $HCO_3$-$SO_4$-Ca. The distribution of the content of individual ions for the Bełchatów Field and the Szczerców Field is shown in Fig. 8 (Krzyszkowski 1986), in which the size of the area of the circle is proportional to the total mineralization (in this case, dissolved sub-stances) in the relation 1 $mg/dm^3$ = 0.5 $mm^2$.

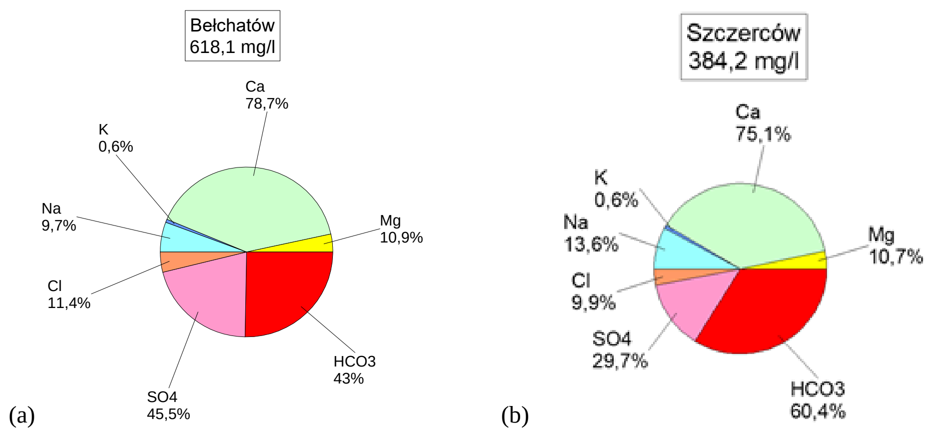

Fig. 8. This is a figure. Schemes follow another format. If there are multiple panels, they should be listed as: (a) description of what is contained in the first panel. (b) description of what is contained in the second panel. Figures should be placed in the main text near to the first time they are cited

The chemistry of waters pumped from the lowest parts of the deposit in the Bełchatów Field changes according to the theory of hydrogeochemical zonation. A higher proportion of deeper circulating waters was revealed in fault zones and tectonic loosening. Increase of the depth of groundwater drainage caused an increase in chloride ion content, with a calculated chloride concentration gradient of 14 ± 2 $mg/dm^3$/10 m of depression. This is directly related to the tectonics of the bedrock of the Mesozoic Kleszczów Trench.

Similarly to the Szczerców Field, a chloride anomaly caused by increased ascension of deeper circulation waters was noted in the area of the marginal fault on the northern side of the tectonic trench. The first signals of increased inflow of deeper circulation waters occurred in 1997, which was reflected by chloride concentrations of 80 $mg/dm^3$ (i.e., 5 times increase compared to the background) in particular wells (Martyniak et al. 2009).

The wells on the southern slope do not indicate any changes of the water chemistry. Throughout the whole period waters with an unchanged type of $HCO_3$-Ca mineralization at concentrations not differing from the hydrochemical background values has been pumped. The same type of mineralization is maintained in the southern part of the protective barrier of the Dębina salt dome. The wells pump waters whose small chloride and sulfate mineralization does not have a share of a component that has hydraulic contact with the formations surrounding the salt body and these are waters in contact with con-temporary infiltration waters (Martyniak et al. 2009).

## 5. CONCLUSIONS

The twenty-year operation of the dewatering system in the Szczerców Field has changed the ionic composition of the pumped waters from a two-ion type $HCO_3$-Ca to a three-ion type $HCO_3$-$SO_4$-Ca.

Across the entire Szczerców Field area, mineralization of the Ca-$SO_4$ type is a consequence of an advanced process of underground oxidation of sulfide minerals.

Throughout the Szczerców Field, the increase in sulfate content is caused by favourable natural conditions for underground oxidation of sulfide minerals, which is confirmed by the isotopic composition of sulfates. In the examined wells, oxygen isotope values are negative ($\delta^{18}O < 0$ [‰ VSMOW]), which is a characteristic feature of the geogenic origin of sulfates.

Long-term and systematic monitoring of water quality provides grounds to conclude that waters from the Szczerców Field dewatering system are characterized by long-term stability in Na-Cl ion concentrations.

After 20 years of operation, only a slight dynamics of changes in the chemical characteristics of waters pumped by the Szczerców Field dewatering system is observed. Over the years, the overall composition of the main ions in pumped waters has remained within the range of a single standard deviation.

Before the start of dewatering in the Szczerców Field, radon activity in Paleogene and Mesozoic aquifer waters was low, not exceeding CRn-222 < 0.2 Bq/dm$^3$.

The study of natural radon and radium content conducted in 2020 shows an increase in their activity, which is a symptom of improved diffusion conditions and indicates an increased contribution of vertical inflow from deeper circulating waters.

Results from the entire groundwater monitoring period confirm that the sulfate reduction process in sub-seam waters progressed faster than in waters directly influenced by infiltration of modern atmospheric precipitation – as shown by the decrease in tritium activity from 6.8 TU to 1.2 TU.

Isotopic analyses of sulfates, tritium content, and concentrations of trace elements (e.g., bromine) indicate that the chemistry of waters pumped for 45 years by the Bełchatów deposit dewatering system is not influenced by waters in contact with the salt-dome structure.

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