

The presence of geogenically saline waters in the area of salt dome Rogóźno (central Poland)

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Abstract: Rogóźno salt dome is one of the most recognizable diapirs in the Polish Lowland. Despite its shallow occurrence depth, increased salinity has not been detected in surface water. The presented hydrogeochemical research aimed at determining if there is the presence of increased geogenical salinity in the groundwater and shallow water. Increased geogenical salinity has not been detected in the Moszczenica River and the Czernańska River, but were displayed in the Moszczenica River valley in the specific electrical conductivity (SEC) spatial distribution. Hydrogeochemical research indicated the presence of a higher mineralized water ascent in the north-eastern part of the dome. The presence of mixing of saline waters around the dome with fresh waters was determined. Ionic composition and hydrochemical indexes of waters sampled from different levels indicate that the saline structure is not completely isolated from surrounding waters. The dome structure is in contact with water from Upper Jurassic formation which influences the final water composition. Active anthropogenic processes partly mask the influences of geogenic salinity in the study area.

Keywords: Rogóźno salt dome, geogenical saline waters, hydrochemical indexes, the Moszczenica River

INTRODUCTION

Late Permian (Zechstein) salt deposits in Central Poland occur as domes, pillows, walls and diapirs, with a height of up to 7 km (Czapowski & Bukowski 2012). Elastic salt masses, due to local disturbances in overburden, started moving towards the surface in the Upper Trias (Tarka 1992). The dome in Rogóźno is one of the diapirs in the Łódzkie voivodeship which completely broke through Upper Mesozoic formations (Fig. 1) (Stelmaszczyk 1972, Czapowski & Bukowski 2012). Although it was recognized as one of the biggest salt domes of the Polish Lowlands (Tarka 1992), it has not yet been effectively recognized in geological terms (Czapowski & Bukowski 2009).

Natural leakage of saline waters has been observed in shallow areas of saline formations (e.g. in Inowrocław or Ciechocinek – see Tarka 1992,

Jodłowski 1997). The presence of saline waters and salt brewing in the area of Łęczycza and Solca Wielka the Łódzkie voivodeship have been dated as early as the 13th century (Fig. 1) (Jodłowski 1977), and continued in Solca Wielka and Pełczyska until the 18th century (Kolago 1965). Natural leakage of saline waters in these areas has also been observed in contemporary times. Intensive settlement and highly-developed metallurgical and milling activity was documented in the Iron Age and Middle Ages in the Moszczenica River valley, which is the biggest river flowing over the central part of the dome. Pottery, cinders and metallurgical products, as well as remains of mills and smithies were found, for example in Gieczno, Rogóźno, Besiekierz (Fig. 1) (Kamiński 1993). The first information about bigger towns located in the dome area comes from the period between the 14th and 16th century (Dylik 1948, Tynenski et al. 2007). There

is no evidence of the use of saline water in the area of dome, both in the archeological material and historical documents. Currently, there is no natural flow of saline waters in this area as well.

Soil chemical features also provide evidence of being influenced by salinity from saline diapirs. Typically saline soil is not common in the Rogóżno area. In the Łódzkie voivodeship it is present only in the previously described areas of saline natural flows around Łęczycza, Pełczyska and Solca Wielka (Czerwiński 1996, Hulisz 2007a, 2007b).

Halophytes, which are plants growing in waters of high salinity, confirm higher soil salinity. Numerous areas of halophytes were present in the areas of Łęczycza and Ozorków (Fig. 1) until the second half of the 20th century. Currently, the smaller presence of halophytes is preserved around Pełczyska (Kucharski 2009, Mróz 2010). The presence of saline areas with halophytes in the salt dome area was recognized only in the 60's of 20th century around Rogóżno and Gieczno. Its presence was, most likely, a short-term occurrence related to drilling projects conducted in the area at that time (Jaworski 1964). The flow of drilling fluids and saline waters could have occurred along poorly insulated drilling holes. The effect of the salt dome on the chemical composition of local water has been documented over the saline structure of Uścikowo (Prochazka 1970), and in the area of Rogóżno in the 50's and 60's (Jaworski 1964).

The aim of this research, apart from recognizing chemical features of groundwater in the Rogóżno area, was to analyze the spatial variability of surface water chemistry over the saline structure. This type of surface water analysis has not yet been conducted on saline structures. Based on the results, an attempt was made to establish whether saline water from the dome area could have been mixed with groundwater and surface water. The Moszczenica River valley located over the salt dome, along with surrounding hydrographic features (ponds, ditches, oxbow lakes) provide very good conditions for conducting such analyses.

GEOLOGICAL SETTINGS

Rogóżno salt dome is located in the Kuyavian-Pomeranian anticlinorium. It was formed similarly to the Łódź sinclinorium – as a result of folding during older phases of Alpine orogeny and halotectonics (Turkowska 2001). The Rogóżno diapir is the center of the anticlinal structure which is surrounded by Mesozoic structures (Fig. 1). The dome borders Jurassic structures from the north-east, whereas from the south-west it borders Cretaceous formations. The anticline of Rogóżno continues in a SE direction, where in the core there is a sequence of embankments around the dome.

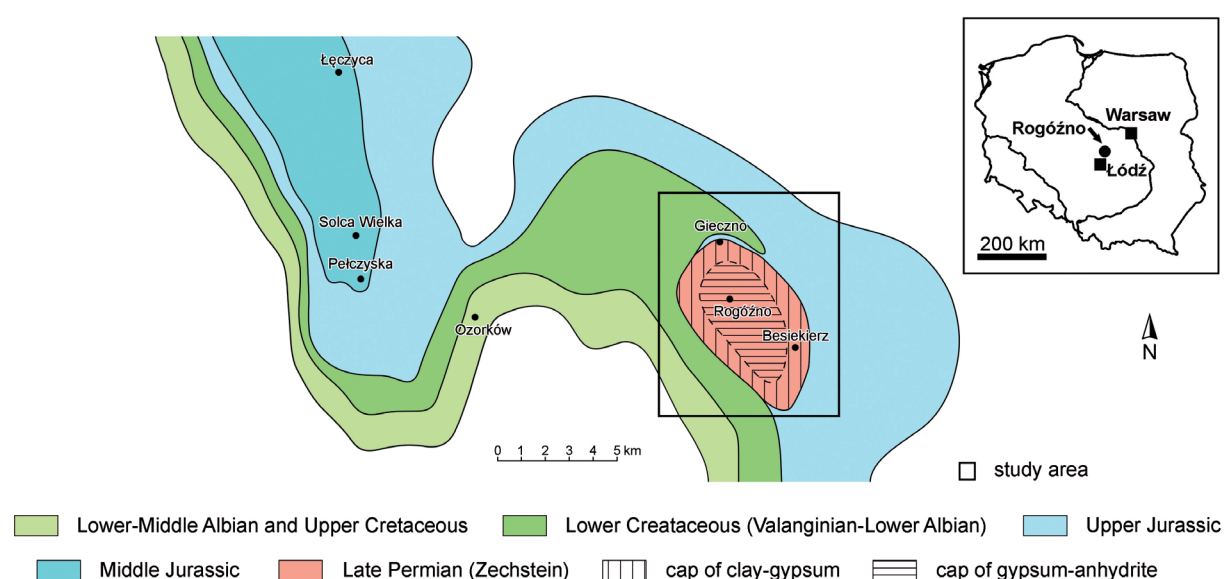


Fig. 1. Geological map of Rogóżno and surrounding areas (after Marek 1957; simplified)

In the plan view, the dome has an ellipsis-like shape, with a longer axis extending in the NW-SW direction which is almost along the anticlinorium of Central Poland (Stelmaszczyk 1972). Rock salt in Rogóżno is composed of 97.8% of NaCl; estimated rock salt resources to the maximum depth of 1000 m have been calculated at 8.6 trillion tons (Czapowski, on-line). The saline structure has a volume of around 120 km³ (Tarka 1992).

The thickness of the cap over the salt dome Rogóżno varies from 13 m in the northern part to 286 m in the south-eastern part (Stelmaszczyk 1972). Gypsum-anhydrite residuum was found in the central part, whereas loam and gypsum were found on its borders (Jaworski 1962). In the gypsum-anhydrite part, karst processes developed greatly. Karstification of the cap already occurred, most probably in the younger Tertiary. It is evidenced by the discontinuous layers of Eocene lignite present in only some of the sinkholes. Also, layers of Miocene lignite are discontinuous and they are only present in a few more significant depressions. It is evidence that the karstification of the cap was not completed in the Tertiary, but also continued in Pleistocene and may also have continued to occur in modern times. The process of the karstification of the cap contributed to the surface modification of the glacial till of the Warta. The deep buried forms and present valley of the Moszczenica River are related to karst processes taking place in the gypsum-anhydrite cap, especially in its central part (Kamiński 1993). There is a co-dependancy observed between the course of river valley and lowering in ceiling of Tertiary residuum. It is possible that deep and narrow erosive indentations in clay are related to karst lowering in the dome cap, repeated in the following geological periods (Kamiński 1993). Aragonite, a mineral rarely present in Poland and which has never been found in any saline residue of Polish Lowlands, was found in Rogóżno. Aragonite is, most probably, evidence of gypsum leaching (Jaworski 1962); after all, the process of leaching is especially intense in the environment reach in saline waters (Pazdro & Kozerski 1990).

Cenozoic residue, which is present over the loam-gypsum alluvium, includes formations from the Paleogene, Neogene and Quaternary. The thickness of formations, previously classified as Tertiary, greatly varies in the cap basin; with the

bottom of the formation being more diversified than formation top (Klatkova 1993). Quaternary residues cover continuously the entire area with a layer of variable thickness (Turkowska 2001). The Quaternary residue thickness over the dome also varies greatly. Such diversity of thickness is a reflection of the elevation variability of the Tertiary top, and more levelled present topographic surface. Additionally, xenolithes, floes of Tertiary formations, marlstones and chalky limestones are among the Quaternary formations. They are most commonly present in areas of intensive glaciotectionic disturbances (Klatkova 1993).

Mesozoic formations protect the salt pillar from dissolution. The contact between the salt and Mesozoic residue is strictly tectonic. There is a fault-flexure dislocation along the south and south-western border of the dome. It cuts and covers Mesozoic formations (from Trias to Lower Cretaceous-Valanginian). The dislocation zone on the east border of the dome is slightly lower. Residues of Upper Jurassic are in discordant contact with Zechstein formations, starting from Kimmeridgian (Stelmaszczyk 1972). The Jurassic is represented by the Late Jurassic limestones. There are Quaternary outcrops of Upper Jurassic limestones (Klatkova 1993) in the Gieczno and Besiekierz area (the eastern and northern side of the dome). Late Jurassic limestones on the western side of the diapir are covered with the overhang of loam-gypsum cap and a thin layer of Lower Cretaceous which was only detected on the western and southern border of the dome (Stelmaszczyk 1972).

HYDROGEOLOGICAL AND HYDROLOGICAL SETTINGS

Intense tectonic, saline, glaciotectionic disturbances or karstification occurring in the area of the salt dome contribute to a complicated circulation system of groundwater flow. In some areas, groundwater flow of highly-mineralized water from deeper aquifers is displayed in the near-surface water flow system. There is a local, direct contact between aquifer Quaternary formation with Tertiary sands in Gieczno area (Miocene and possibly older) (Stelmaszczyk 1972). Water from Quaternary and Tertiary aquifers in the Rogóżno area are so interconnected that they might be considered to be one Miocene-Quaternary aquifer.

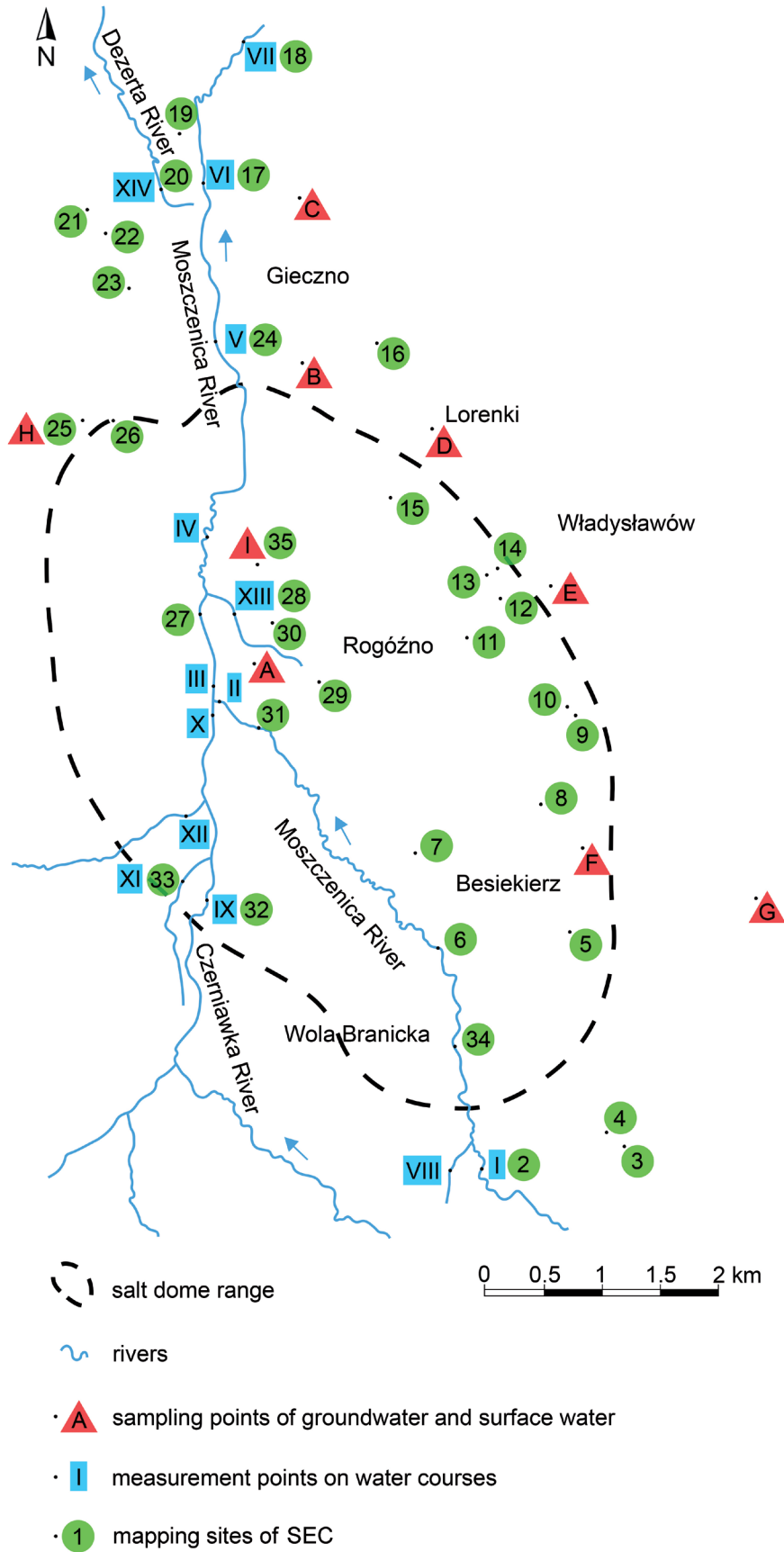


Fig. 2. Documentation map of Rogóźno region

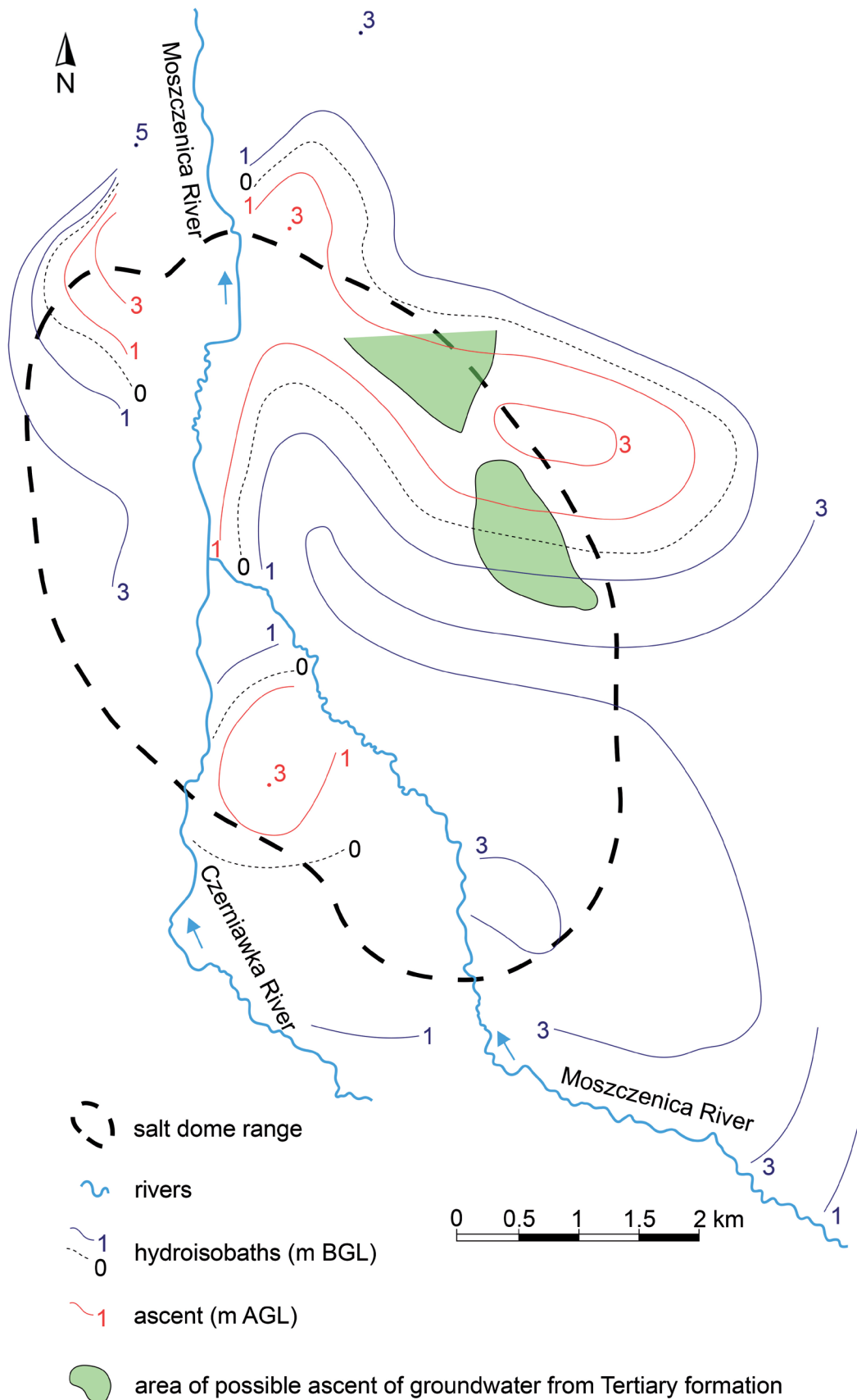


Fig. 3. Area of possible ascent of groundwater from Tertiary formation against the system of hydroisobaths of the first deep Quaternary level

Contact between this aquifer and water from Permian formation (*Dokumentacja...*, 2002) is probable. The Miocene level, connected with sands separating layers of lignite from different eras had, most probably, a hydraulic contact with a salt deposit (Stelmaszczyk 1972) connects with groundwater from the Permian formation. Groundwater around the dome (Permian system) may be accumulated in voids and fractures between the saline water table and a dense gypsum cap. The gypsum cap is, most likely, not always in direct contact with the saline water table and it creates a ceiling above washed-out parts of the salt dome. Frequently the higher part of residuum occurs as chaotic debris of gypsum and anhydrite with residues of salt, gypsum marlstone and loam. Such rubble, containing many empty voids, can be partially or completely filled with eluvial silt up before it becomes a compact rock mass. Saline water can be accumulated when these voids are completely filled with sediment (Szaniawski 1963). There is lateral contact between water from Upper Jurassic aquifer and saline water from Zechstein aquifer behind the northern and north-western border of the dome (Meszczyński & Szczerbicka 2002). The high temperature of water from the Upper Jurassic aquifer indicates flow system from a greater depth that eventually accumulates in Jurassic limestones. Because of the neighboring salt dome, limestones were piled, disturbed tectonically and cracked. Covered with an impermeable loam-gypsum cap, they became a suitable reservoir for accumulating warm water flowing from below (Stelmaszczyk 1972).

The analysis of the Quaternary and Tertiary hydroisobaths is indicated in areas of Władysławów and Lorenki potential ascent zone (Figs. 2, 3) (Górecki 2015).

The Moszczenica River serves as a draining base level of shallow aquifer flow systems. Aquifers, present in Quaternary formations, form a local water circulation system while deeper aquifers (Tertiary and Upper Jurassic) form a regional system draining to the Bzura River valley on WNW from the dome (Bierkowska & Błaszczuk 1989).

Moszczenica is the biggest river draining the northern part of the Łódź Hills. It is 56 km long and is a tributary of the Bzura River. Czerniawka, its biggest tributary, flows into the Moszczenica River in the Rogóźno area (Fig. 2). Moszczenica

River and Czerniawka River are characterized with moderately developed nival regime which, in this area, is characterized by balanced groundwater and surface flow components in total outflow (Jokiel 2004). The highest flow in these rivers is noted at the turn of March and April, and the lowest at the turn of September and October (Maksymiuk 2001).

A little over 1/3 of the Moszczenica River length and over 1/2 of the Czerniawka River length are located in the area of salt dome Rogóźno. Apart from Moszczenica and Czerniawka rivers, there are nameless surface streams in the area, with the total length of about 3 km. In the dome area, the density of river system is relatively higher and amounts to about $0.579 \text{ km}\cdot\text{km}^{-2}$ (Szaniawski 1963), which means it is similar to the maximum amount in Central Poland $-0.6 \text{ km}\cdot\text{km}^{-2}$ (Jokiel 2004).

METHODOLOGY OF FIELD RESEARCH ON SURFACE WATERS

The analysis of hydrochemical conditions around the Rogóźno salt dome was conducted in selected observation points on the following rivers: the Moszczenica River, the Czerniawka River and their tributaries. Selection of sample-control points was performed strictly according to Inspectorate of Environmental Protection regulations (Gołębiowska et al. 1994), taking into consideration specificity of local conditions. 14 water samples were collected: seven from the Moszczenica River, two from the Czerniawka River and one of each of the tributaries (Fig. 2, Tab. 1). Water temperature (T), pH and SEC were measured at every point. Additionally, water levels (H) were monitored in the gauge station of the Institute of Meteorology and Water Management in Moszczenica-Gieczno.

Other hydrographic features in Moszczenica River valley include oxbow lakes and mires, and artificial ponds and ditches. Spatial distribution of SEC was used to evaluate total mineralization changes in all types of surface waters as this parameter is a good indicator of changes in the water chemical composition (Witczak et al. 2013). Hydrochemical mapping was conducted at the end of August 2014 a period characterized by low-flow regime (Fig. 4). Measurements were taken in rivers and streams with continuous flow as well as in non farming ditches and ponds (Fig. 2, Tab. 2).

Table 1
Characteristics of measurement points along the rivers

| Number of point | Geographical coordinates (N, E) ^A | Name of the river, watercourse ^A | Length [km] | Description of a location |
|-----------------|--|---|---------------------|---|
| I | 51°55'55.3" 19°28'40.2" | Moszczonica | 30+500 | a bridge in Michałów |
| II | 51°58'08.1" 19°26'35.4" | Moszczonica | 23+400 | before mouth the Czerniawka River in Kotowice |
| III | 51°58'13.1" 19°26'34.1" | Moszczonica | 23+300 | after mouth the Czerniawka River in Kotowice |
| IV | 51°58'42.4" 19°26'29.7" | Moszczonica | 22+200 | a meander in Kotowice |
| V | 51°59'49.0" 19°26'35.2" | Moszczonica | 19+500 ^B | a stream gauge in Gieczno |
| VI | 52°00'34.2" 19°26'27.4" | Moszczonica | 17+700 | a bridge in Borowiec |
| VII | 52°01'15.5" 19°26'42.4" | Moszczonica | 15+900 | a bridge on the dirt road in Sypin |
| VIII | 51°55'54.2" 19°28'25.8" | nameless watercourse | 0+400 | a culvert under the road in Wola Branicka |
| IX | 51°57'11.2" 19°26'33.2" | Czerniawka | 1+800 | a bridge on the voivodeship road 708 in Bądków |
| X | 51°58'07.1" 19°26'33.3" | Czerniawka | 0+100 | before mouth into the Moszczonica River in Kotowice |
| XI | 51°57'15.5" 19°26'21.1" | nameless watercourse | 0+400 | a culvert under the voivodeship road 708 in Bądków |
| XII | 51°57'35.5" 19°26'20.8" | creek with Jasionka | 0+200 | a bridge on the dirt road in Kotowice |
| XIII | 51°58'31.9" 19°26'44.4" | oxbow Moszczonica | 0+400 | a bridge on the road in Kotowice |
| XIV | 52°00'32.8" 19°26'07.1" | Dezerta | 4+100 | a bridge on the dirt road in Borowiec |

Explanations: number of point according to Figure 2; ^A - based on Czarnecka 2005; ^B - length for the stream gauge in Gieczno (based on Szczepański 1995–1996).

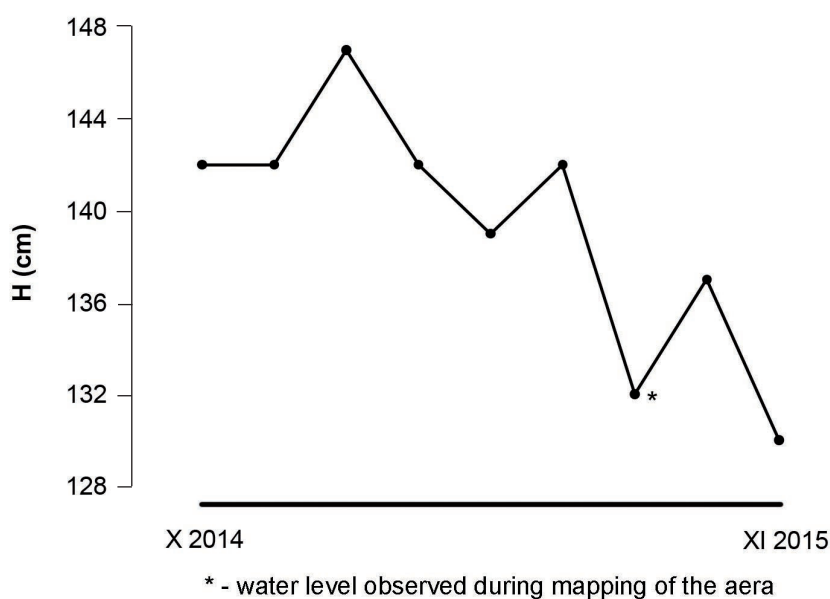


Fig. 4. Water level (H) in the Moszczonica River in Gieczno during period October 2014 –November 2015

Table 2
Mapping sites of specific electrical conductivity (SEC)

| Number of point | Geographical coordinates (N, E) | Description of a location | Number of point | Geographical coordinates (N, E) | Description of a location | Number of point | Geographical coordinates (N, E) | Description of a location |
|-----------------|---------------------------------|---------------------------|-----------------|---------------------------------|---------------------------|-----------------|---------------------------------|---------------------------|
| 1 | 51°55'54.2" 19°28'25.8" | ditch | 13 | 51°58'42.7" 19°28'40.1" | ditch | 25 | 51°59'27.7" 19°25'30.9" | ditch |
| 2 | 51°55'55.3" 19°28'40.2" | the Moszczenica River | 14 | 51°58'43.5" 19°28'41.9" | pond | 26 | 51°59'26.7" 19°25'46.8" | pond |
| 3 | 51°56'03.8" 19°29'41.8" | pond | 15 | 51°59'07.0" 19°27'58.7" | ditch | 27 | 51°58'30.8" 19°26'28.5" | the Moszczenica River |
| 4 | 51°56'06.8" 19°29'37.4" | ditch | 16 | 51°59'51.1" 19°27'47.7" | ditch | 28 | 51°58'31.9" 19°26'44.4" | ditch |
| 5 | 51°57'09.9" 19°29'23.5" | pond | 17 | 52°00'34.2" 19°26'27.4" | the Moszczenica River | 29 | 51°58'17.2" 19°27'22.0" | pond/peatbog |
| 6 | 51°56'59.5" 19°28'17.1" | the Moszczenica River | 18 | 52°01'15.5" 19°26'42.4" | the Moszczenica River | 30 | 51°58'32.1" 19°27'02.3" | pond |
| 7 | 51°57'39.4" 19°28'00.4" | pond | 19 | 52°00'55.5" 19°26'15.0" | pond | 31 | 51°57'59.7" 19°26'55.6" | the Moszczenica River |
| 8 | 51°57'39.4" 19°29'03.4" | ditch | 20 | 52°00'32.8" 19°26'07.1" | the Dezerta River | 32 | 51°57'11.2" 19°26'33.2" | the Czerniawka River |
| 9 | 51°58'04.9" 19°29'19.9" | pond | 21 | 52°00'30.1" 19°25'38.8" | pond | 33 | 51°57'15.5" 19°26'21.1" | ditch |
| 10 | 51°58'05.7" 19°29'17.4" | pond | 22 | 52°00'20.2" 19°25'43.9" | pond | 34 | 51°56'32.2" 19°28'29.1" | the Moszczenica River |
| 11 | 51°58'28.3" 19°28'32.4" | pond | 23 | 52°00'04.5" 19°25'54.0" | pond | 35 | 51°58'13.5" 19°26'55.5" | pond |
| 12 | 51°58'32.6" 19°28'54.5" | pond | 24 | 51°59'49.0" 19°26'35.2" | the Moszczenica River | | | |

Explanations: number of point according to Figure 2.

METHODOLOGY OF FIELD RESEARCH ON GROUNDWATER

The initial analysis of hydrogeochemical conditions in the dome area was conducted on the basis of data coming from 65 hydrogeological observation points (piezometers and wells). The main source of information was the HYDRO Bank data base of the Polish Hydrogeological Survey and the archives of Department of Geology and Geological Concession of the Marshal Office of Łódzkie Voivodeship. Collected hydrochemical data came from the following formation: Quaternary (45 cases), Tertiary (11), Upper Jurassic (6) and Permian residue (3). A relationship between the Cl^- concentration and water total mineralization in water from Tertiary and Upper Jurassic formations with the R^2 value close to unity was observed.

Based on archive data, the chloride baseline of water from Quaternary formation for Rogóżno salt dome was established ($n = 45$). The boundary for the baseline was the concentration of Cl^- corresponding to the difference between one standard deviation and estimated parameter median value (68% of observation) (Zdechlik & Kania 2003). The lower limit of chloride baseline is $7 \text{ mg} \cdot \text{dm}^{-3}$, whereas the higher $90 \text{ mg} \cdot \text{dm}^{-3}$.

Some of the wells accumulating water from the Quaternary formation display an anomalous

concentration of chloride ions (Fig. 5). Several- or dozen times higher concentration of Cl^- in comparison with the higher limit may indicate the presence of migration of saline water into the near-surface area.

In order to establish the scale of salinity of groundwater and its origin, the hydrogeological documentation and marked zones of upward flow of mineralized waters into surface (Fig. 3) was used. A group of hydrogeological formations was selected for the research. The respective criteria were taken into consideration while choosing suitable wells:

- whether accumulated waters indicate higher value of total mineralization or chlorides,
- the close or nearby location of hypothetical zones of saline waters (Fig. 3),
- technical condition enabling the possibility of sampling.

According to the criteria above, six wells and two piezometers were selected (Fig. 2, Tab. 3). One pond was also included as, according to archival data, it was close to the possible upward flow area of the saline waters, strictly connected to a nearby drilling hole. Well and pond sampling included measurements of water temperature (T), pH, SEC and reduction-oxidation potential (Eh). An overflow chamber was used in the measurement to protect the water from contact with air.

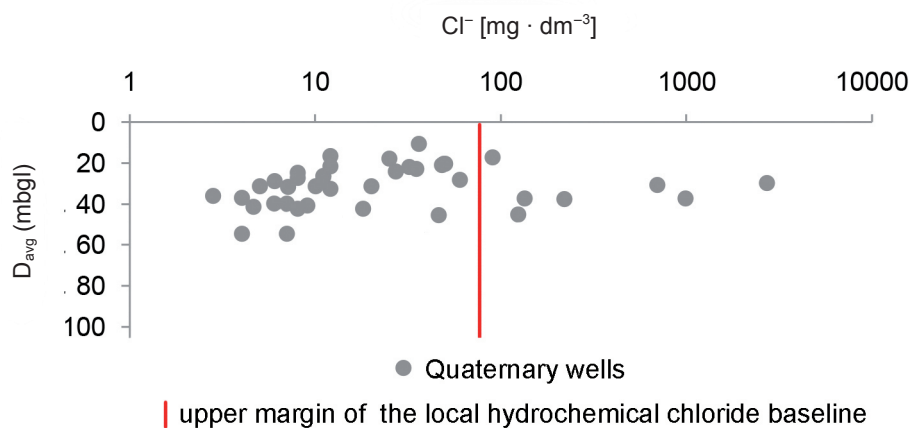


Fig. 5. Change in concentration of chloride ion (Cl^-) in groundwater from Quaternary formation (D) in the area of Rogóżno salt dome with respect to the upper margin of the local hydrochemical chloride baseline

Table 3
Characteristics of groundwater and surface water sampling points

| Number of well according to Figure 2 | Number of well according to CBDH | Geographical coordinates of well (N, E) | Depth of well [m] | Filtering compartment [m] | Age of aquifer | Allocation | Artesian flow | User |
|--------------------------------------|----------------------------------|---|-------------------|---------------------------|----------------|------------------------------------|---------------|----------------------------------|
| A | - | 51°58'13.5" 19°26'54.6" | n.d. | n.d. | Q | observation of groundwater quality | - | "Moya" petrol station |
| B | 5 900 371 | 51°59'45.1" 19°27'14.6" | 70.0 | 52.0-70.0 | J | irrigation | + | poultry farm |
| C | - | 52°00'17.9" 19°27'07.4" | 6.2 | 1.5-5.0 | Q | observation of groundwater quality | - | "Janisz" petrol station |
| D | 5 900 618 | 51°59'35.3" 19°28'12.5" | 18.5 | 16.2-18.0 | Q | not in use | - | "Markie-Pol" firm |
| E | 5 900 412 | 51°58'42.6" 19°28'57.7" | 41.0 | 35.0-39.0 | Q | not in use | - | former milk-collection |
| F | 5 900 325 | 51°57'27.8" 19°29'28.5" | 103.0 | 69.5-103.0 | J | not in use | + | former agricultural cooperative |
| G | 5 910 356 | 51°57'14.3" 19°30'49.3" | 150.0 | 56.6-150.0 | J | n.d. | - | "Salio" horse-riding club |
| H | 5 900 348 | 51°59'27.6" 19°25'33.0" | 241.4 | 238.5-241.4 | J | not in use | + | "Gieczynska" former water intake |
| I | - | 51°58'13.5" 19°26'55.5" | - | - | - | pond | - | private person |

Explanations: CBDH – Central Hydrogeological Databank (Centralna Baza Danych Hydrogeologicznych); n.d. – no data; Q – Quaternary; J – Upper Jurassic

METHODOLOGY OF LABORATORY RESEARCH

Apart from the measurement of physicochemical parameters *in situ*, samples of water for laboratory analysis were taken in order to evaluate the presence of the following ions:

- in the case of water sampled from river: Cl^- and Na^+ ;
- in the case of groundwater and the pond: anions (Cl^- , HCO_3^- , NO_3^- , NO_2^- , SO_4^{2-} , PO_4^{3-}), cations (Na^+ , K^+ , NH_4^+ , Ca^{2+} , Mg^{2+} , Mn^{2+} , Fe^{2+}), and a total amount of dissolved substances of total carbonate and non-carbonate hardness.

Six hydrochemical ratio indexes were used to interpret the chemical composition of groundwater: [1] sodium vs. chloride, [2] sodium vs. sodium and chloride, [3] calcium vs. magnesium, [4] bicarbonate vs. chloride, [5] ESP (Exchange Sodium Percentage), and [6] SAR (Sodium Adsorption Ratio) (e.g. Macioszczyk 1987, Hounslow 1995, Razowska 1999). Their calculation was based on the content of ions in the equivalent form.

- [1] **Sodium vs. chloride index:** $\frac{\text{Na}^+}{\text{Cl}^-}$ establishes the level of water metamorphosis and its isolation from the area, as well as from other aquifers. With the lowering of the index, water becomes older and the levels of metamorphosis and isolation become higher (Macioszczyk 1987, Pazdro & Kozerski 1990).
- [2] **Sodium vs. sodium and chloride index:** $\frac{\text{Na}^+}{\text{Na}^+ + \text{Cl}^-}$ along with water total mineralization helps determining the sources of sodium in water (Hounslow 1995).
- [3] **Calcium vs. magnesium index:** $\frac{\text{Ca}^{2+}}{\text{Mg}^{2+}}$ helps in establishing if low-mineralized groundwater are contaminated by calcium or magnesium fertilizers (Macioszczyk 1987).
- [4] **Bicarbonate vs. chloride index:** $\frac{\text{HCO}_3^-}{\text{Cl}^-}$ assess length of the flow of water from the recharge area. A low value of the index means water staying in the rock formation for a longer time (Winid & Lewkiewicz-Małysa 2005).
- [5] **Exchange Sodium Percentage:** $\text{ESP} = \frac{(\text{Na}^+ + \text{K}^+) \cdot 100}{\text{Ca}^{2+} + \text{Mg}^{2+} + \text{Na}^+ + \text{K}^+}$ [%] establishes the usefulness of water for irrigation purposes. Water with high ESP index may contain colloids and suspensions which have a negative effect on soil permeability (Singh et al. 2014).

- [6] **Sodium Adsorption Ratio:** $\text{SAR} = \frac{\text{Na}^+}{\sqrt{(\text{Ca}^{2+} + \text{Mg}^{2+})/2}}$ expresses relative activity of sodium in exchange reactions with the water impact on soil. The higher the index, the easier it is for Na^+ to transfer to a sorption complex. At the same time, the probability of high soil salinity increases. The parameter the alkalinity of water as well (Kwaterkiewicz & Sadurski 1986, Ochman et al. 2011, Singh et al. 2014).

It was assumed that if the areas of higher water total mineralization and higher concentration of chloride ions overlap with areas where the upward flow of water from deeper levels, the salt dome influences water chemistry in the Moszczenica valley. The interpretation of the ion composition of groundwater on the basis of hydrochemical indexes allowed the origin of salinity to be determined.

RESULTS

Local hydrological conditions during field studies refer to Moszczenica River level on the water gauge in Gieczno in the range of 130–147 cm (Fig. 4) which, according to Szczepański 1995, is a low level. These numbers correspond to the river flow from $0.62 \text{ m}^3 \cdot \text{s}^{-1}$ to $1.06 \text{ m}^3 \cdot \text{s}^{-1}$ (according to the Institute of Meteorology and Water Management); which represent average level in this part of the river (Szczepański 1995).

The minimum and maximum values of examined physico-chemical parameters observed on measure-control gauges are represented in Table 4. There is a continuous pattern in examined physico-chemical parameters of water in the middle course of the Moszczenica River. Prior to connection with the tributary Czerniawka River, the average statistical water chemistry data and their range were relatively high. After the waters are combined, the parameters are lower and the range between them is reduced, then increased again in the lower part of the Moszczenica River (Fig. 6A–C).

The analyzed SEC area in surface waters undergoes important changes (Fig. 7). The area of lower than $400 \mu\text{S} \cdot \text{cm}^{-1}$ is located along Moszczenica River channel and the upper part of Czerniawka River. SEC of surface waters increases with a growing distance from the Moszczenica River.

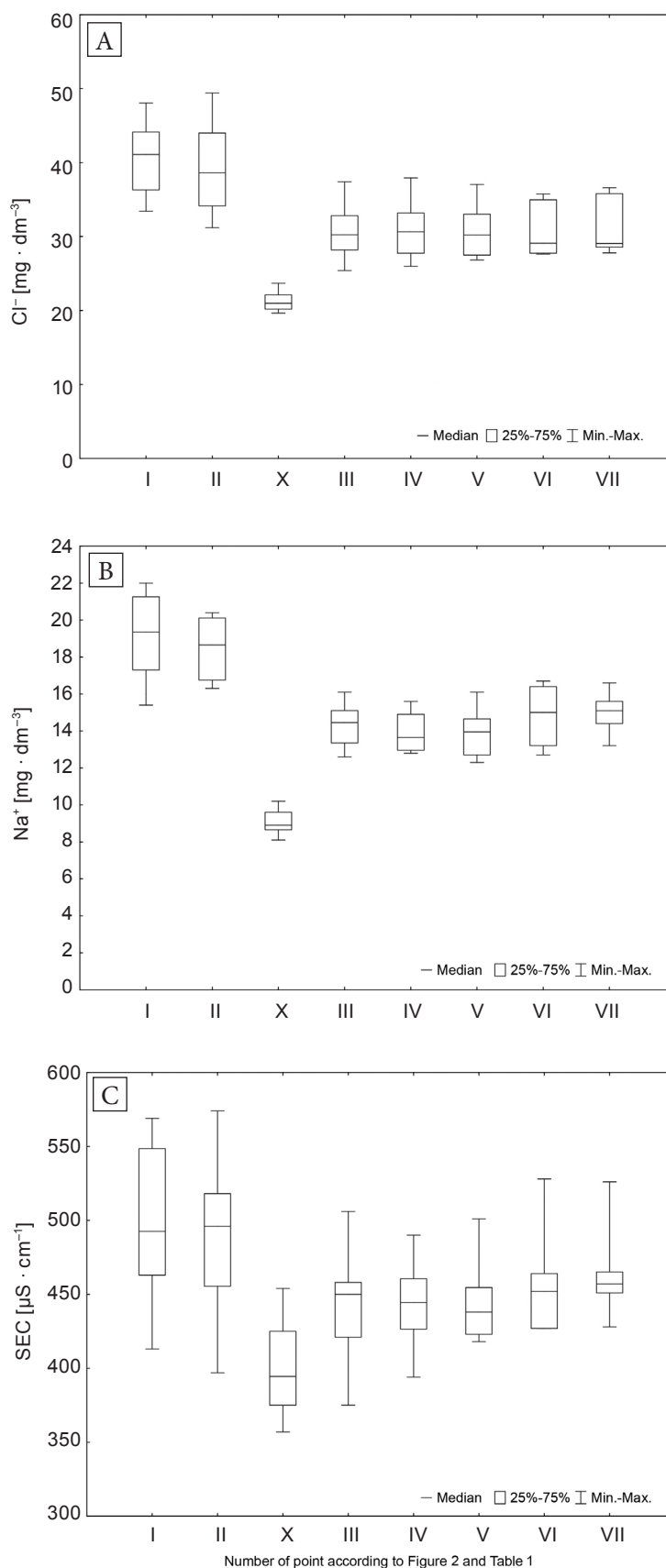


Fig. 6. Statistical distribution of chloride ion (Cl^-) in measure-control points in the Moszczenica and the Czerniawka rivers (A); statistical distribution of sodium ion (Na^+) in measure-control points in the Moszczenica and the Czerniawka rivers (B); statistical distribution of specific electrical conductivity (SEC) in measure-control points in the Moszczenica and the Czerniawka rivers (C)

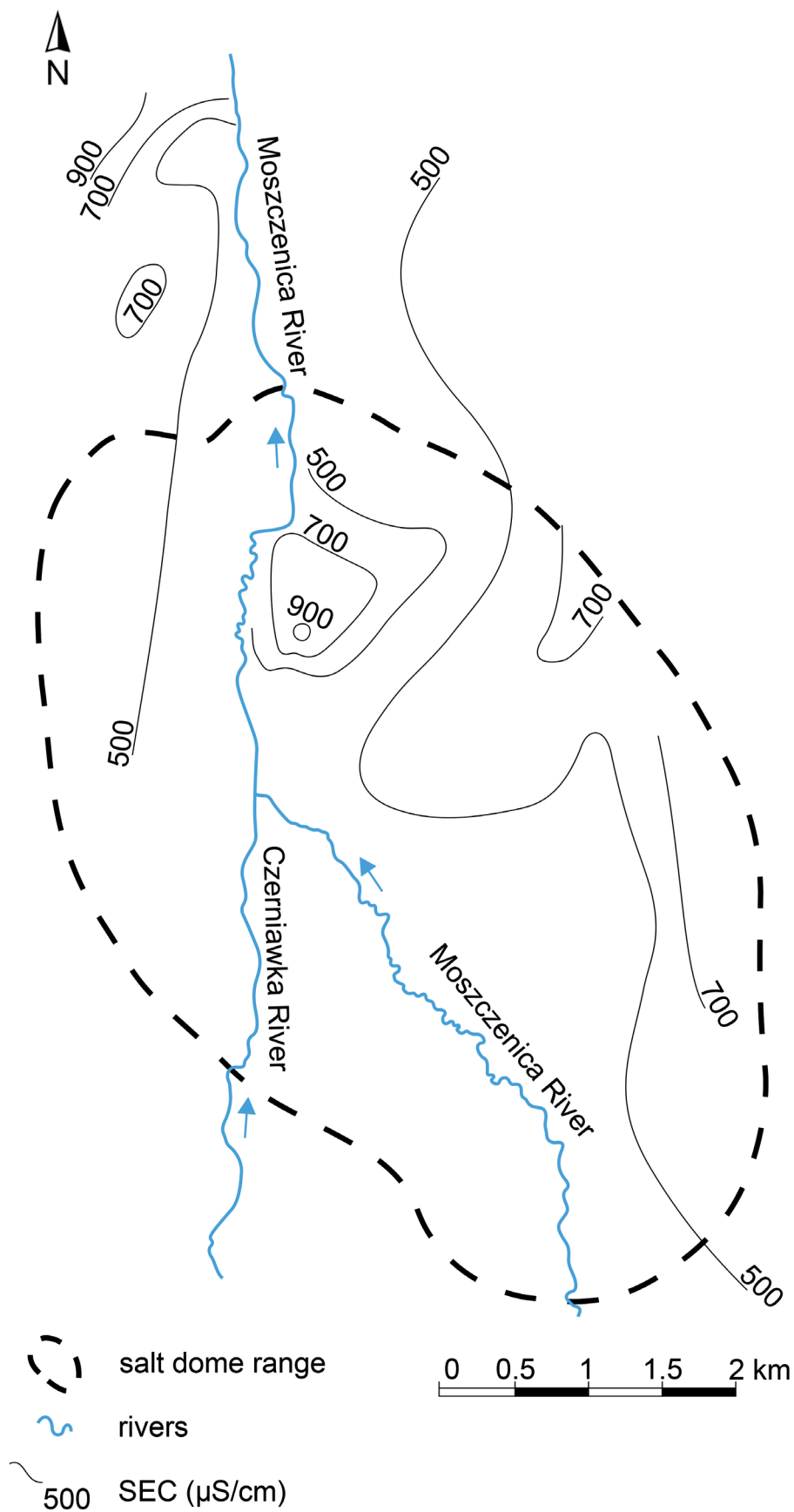


Fig. 7. Changes in conductivity (SEC) of surface water in the Rogóźno region

Table 4

Minimum and maximum values of selected hydrochemical elements of examined rivers in selected measure-control points

| Objects (n) | pH | | SEC [$\mu\text{S}\cdot\text{cm}^{-1}$] | | Cl ⁻ [$\text{mg}\cdot\text{dm}^{-3}$] | | Na ⁺ [$\text{mg}\cdot\text{dm}^{-3}$] | |
|--|------|------|--|-----|--|------|--|------|
| | min | max | min | max | min | max | min | max |
| All objects (14) | 4.77 | 8.75 | 317 | 639 | 14.0 | 49.4 | 4.9 | 27.4 |
| Points on the Moszczenica River (7) | 7.11 | 8.75 | 375 | 579 | 25.4 | 49.4 | 12.3 | 22.0 |
| Points on the tributaries of the Moszczenica River (7) | 4.77 | 8.54 | 317 | 639 | 14.0 | 45.5 | 4.9 | 27.4 |

The highest value of the parameter SEC ($913 \mu\text{S}\cdot\text{cm}^{-1}$) was observed in the pond located in Rogózno. High conductivity contributes to the identification of an anomaly area around the pond, within larger area of relatively consistent spatial variability of SEC. Gradual increase of SEC

is observed in the direction of the Warsaw-Berlin glacial valley, on the western side of the Moszczenica River.

Hydrogeochemical characteristics of sampled objects are presented in Kurlov formula (Tab. 5); supplemented with information on water pH.

Table 5

Chemical analysis of sampled objects on the basis of Kurlov formula

| Number of well | Kurlov formula |
|----------------|--|
| A | $M^{0.3} \frac{\text{HCO}_3^{38} \text{Cl}^{30} \text{SO}_4^{24} \text{NO}_3^7}{\text{Ca}^{62} \text{Na}^{22} \text{Mg}^{10} \text{K}^6} T^{13}, \text{pH}^{6.16}$ |
| B | $M^{2.1} \frac{\text{Cl}^{83} \text{HCO}_3^9 \text{SO}_4^7}{\text{Na}^{87} \text{Ca}^8 \text{Mg}^4 \text{K}^1} T^9, \text{pH}^{7.54}$ |
| C | $M^{0.5} \frac{\text{NO}_3^{50} \text{SO}_4^{26} \text{Cl}^{15} \text{HCO}_3^9}{\text{Ca}^{63} \text{Mg}^{17} \text{Na}^{15} \text{K}^5} T^{14}, \text{pH}^{5.73}$ |
| D | $M^{0.4} \frac{\text{HCO}_3^{56} \text{Cl}^{37} \text{SO}_4^5 \text{NO}_3^2}{\text{Ca}^{54} \text{Na}^{35} \text{Mg}^6 \text{K}^3 \text{NH}_4^2} T^{11}, \text{pH}^{7.24}$ |
| E | $M^{0.6} \frac{\text{HCO}_3^{50} \text{Cl}^{44} \text{SO}_4^5}{\text{Ca}^{47} \text{Na}^{43} \text{Mg}^9 \text{K}^1} T^{10}, \text{pH}^{7.33}$ |
| F | $M^{0.4} \frac{\text{HCO}_3^{68} \text{Cl}^{26} \text{SO}_4^5}{\text{Ca}^{63} \text{Na}^{24} \text{Mg}^{12} \text{K}^1} T^{24}, \text{pH}^{10.7}$ |
| G | $M^{0.3} \frac{\text{HCO}_3^{87} \text{SO}_4^7 \text{Cl}^5 \text{NO}_3^1}{\text{Ca}^{73} \text{Mg}^{13} \text{Na}^{13} \text{K}^1} T^{10}, \text{pH}^{9.39}$ |
| H | $M^{1.0} \frac{\text{Cl}^{86} \text{HCO}_3^9 \text{SO}_4^5}{\text{Na}^{67} \text{Ca}^{26} \text{Mg}^6 \text{K}^1} T^{24}, \text{pH}^{7.84}$ |
| I | $M^{0.8} \frac{\text{Cl}^{47} \text{HCO}_3^{37} \text{SO}_4^{16}}{\text{Ca}^{53} \text{Na}^{34} \text{Mg}^9 \text{K}^4} T^1, \text{pH}^{5.71}$ |

Explanations: number of well according to Figure 2 and Table 3.

Groundwater, with semi-acid pH, flows into the shallowest piezometers. The ionic composition of these waters indicates their relative similarity. The important difference is shown with respect to a dominant anion. Bicarbonates are dominant in water sampled from piezometer (A) whereas nitrates are dominant in water flowing into the piezometer (C).

Quaternary deep wells (D, E) are recharged with waters that do not have total mineralization higher than $600 \text{ mg}\cdot\text{dm}^{-3}$; they consist mainly of bicarbonates, chlorides, calcium and sodium. Other ions are present, but in small concentrations and the temperature and pH of these waters are similar.

Wells collecting water from Upper Jurassic formations can be divided into two groups. Each of these groups is characterized by unique physico-chemical parameters. The first group consists of wells (G) and (F). Water flowing into them is alkaline and of low total mineralization. Water in the well (F) is bicarbonate-calcium dominated by significant concentrations of Cl^- and Na^+ . This well has an artesian flow of about $1.7 \text{ dm}^3\cdot\text{s}^{-1}$ and temperature of 24.0°C . The second group consists of wells (B) and (H). In each of the wells, the groundwater table is stabilized above the surface. In (B) the artesian uplift reaches 0.18 m, whereas in (H) it is about 4.8 m with the simultaneous outflow of water with temperature of 24.0°C . Mineral chloride-sodium waters flow into the well; where in higher rate of calcium is present in the well (H). The chemical analysis indicates that in the pond (I) there is a slightly acidic acratopegae and its main components are: Cl^- , HCO_3^- , Na^+ and Ca^{2+} .

DISCUSSION

Increased flow volumes of the Moszczenica River correlated with decreased pH ($R^2 = 0.7$; Fig. 8A) and an increased concentration of Na^+ ($R^2 = 0.6$; Fig. 8B). There is no observable statistically significant correlation between flow volume and SEC and Cl^- concentration, which could be caused by diverse sources of Cl^- (Mazurek 2000). During high flows, some of the smallest and biggest rates of SEC and Cl^- were observed. The correlation between conductivity and Cl^- ion in water is observed only when concentration of Cl^- is very

high. Correlation between concentrations of Na^+ and Cl^- is good, particularly at high concentrations. In the central and northern stretch of the Moszczenica River, which is within the salt dome area and outside its northern border, there was no significant increase of measured physicochemical parameters (Fig. 6A–C) while significantly higher salinity was observed in its tributary, the Dezerta River. The Moszczenica River, in contrast to other rivers in the region, is characterized with average SEC and concentration of Cl^- ion, which suggests relatively the limited influence of the anthropogenic impact on the water chemistry (*Ocena stanu wód powierzchniowych*, 2013).

SEC overall increases with a increasing distance from the Moszczenica River and the Czerniawka River respectively (Fig. 7). This spatial regularity is disturbed by certain 'anomalous' zones. Elevated SEC anomalies around towns of Władysławów and Lorenki overlap with areas of possible ascent of water from Tertiary formation (Fig. 3) (Górecki 2015). The results obtained from the hydrochemical analyses may suggest the presence of certain zones where saline groundwater coming from the area around the dome are flowing up to the surface.

Six ionic ratios have been calculated based on measured parameters and used to interpret processes influencing water chemistry in specific observation points (Tab. 6). The location of the piezometers (A), (C) next to gas stations, residential areas or farmlands influences groundwater chemistry. Water sampled from the well (A) showed Cl^- concentration of over $42 \text{ mg}\cdot\text{dm}^{-3}$ (Tab. 5). In comparison with the archive data coming from piezometers, the concentration is higher but it is within the range of the hydrochemical baseline which does not point to any anomalous rates of ions in water. The ratio between potassium and sodium is low values and may be an evidence of an anomaly in the aquifer. Other evidence of the anthropogenic impact are the elevated concentrations of SO_4^{2-} , PO_4^{3-} and NO_3^- . The low pH of water is connected to the presence of sulfates in the quantity bigger than 20% mval. Permanent anthropogenic contamination of water is proven by the presence of all mineral forms of nitrogen (NH_4^+ , NO_2^- , NO_3^-), increased content of nitrogen, phosphates and sulfates (Macioszczyk &

Dobrzyński 2002) and cause low values of ionic ratio Na/Cl (index 1), which falsely suggest the presence of a very good and long-lasting isolation from the surface which classifies groundwater as relict, highly metamorphosed. High values of ionic ratio HCO_3/Cl (index 4) in contrast, represent waters in the active recharge zone. Contamination of groundwater might be indicated by ionic ratio HCO_3/Cl . Water sampled from the well (C) contains $176 \text{ mg} \cdot \text{dm}^{-3}$ of NO_3^- ion, which strongly suggests water contamination. This is also

confirmed in the low value of the HCO_3/Cl ratio, which is shown in a low content of bicarbonates (Tab. 5). The low pH of water may be linked to the anomalous content of NO_3^- (Pazdro & Kozerski 1990) while the lack of an impermeable layer and the shallow presence of groundwater contributes to the high level of oxidation-reduction potential ($E_h = 238 \text{ mV}$). However, the environment is transitional, between oxidising and reducing with relatively low pH in the aquifer (Tab. 5) (Witczak et al. 2013).

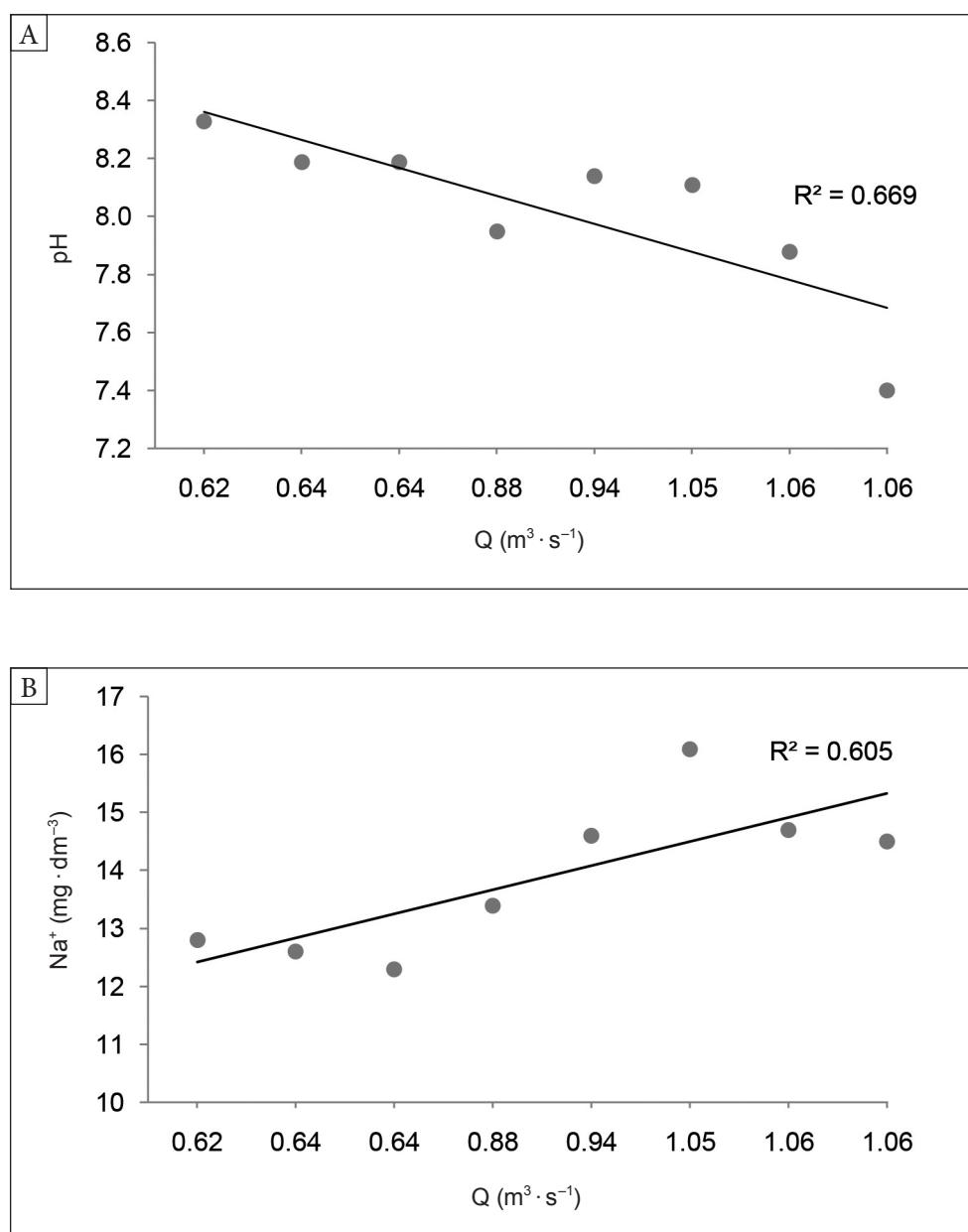


Fig. 8. Correlation between the water flow (Q) and its pH reaction (pH) on Gieczno water gauge (A); correlation between the water flow (Q) and sodium ion content (Na^+) on Gieczno water gauge (B)

Table 6
Characteristics of groundwater and surface waters on the basis of hydrochemical indicators

| Indicator | Interpretation | Number of object | | | | | | | | |
|---|---------------------------------|------------------|----------------|---|---|---|---|---|---|---|
| | | A | B | C | D | E | F | G | H | I |
| $\frac{\text{Na}^+}{\text{Cl}^-}$ | very good insulation | X | | | X | | X | | X | X |
| | good insulation | | X | X | | X | | | | |
| | no insulation | | | | | | | X | | |
| $\frac{\text{Na}^+}{\text{Na}^+ + \text{Cl}^-}$ | halite solution | | X ¹ | | | | | | | |
| | sodium source other than halite | | | | | | | X | | |
| | brine | | X ¹ | X | | X | | | X | X |
| | anthropopressure | X | | | X | | X | | | |
| $\frac{\text{Ca}^{2+}}{\text{Mg}^{2+}}$ | contamination | X | X | | X | | | | | |
| | no contamination | | | X | | X | X | X | X | X |
| $\frac{\text{HCO}_3^-}{\text{Cl}^-}$ | minimal recharge | | X | | | | | | X | |
| | transition zone | | | X | | | | | | X |
| | active recharge | X | | | X | X | X | X | | |
| ESP | suitable for irrigation | X | | X | X | X | X | X | | X |
| | unsuitable for irrigation | | X | | | | | | X | |
| SAR | risk of soil salinity | | X | | | X | | | X | |
| | no risk of soil salinity | X | | X | X | | X | X | | X |

Explanations: number of object according to Figure 2, Table 3 and Table 5; ¹ – ratio value allows for classification into two classes.

The high value of ionic ratio Na/Cl and low value of ionic ratio HCO₃/Cl indicate waters isolated from the surface; such waters have a difficult contact with surface and infiltration waters. However, groundwater is present approximately 2 m b.g.l with no isolating aquifer (the archive of the Łódzkie Voivodeship Marshall Office, catalogue number 1094). The low result of Na/Na+Cl ratio (index 2) with increased total mineralization also improperly characterizes this water as saline originating from geogenical salinity. This waters shows signs of contamination.

The deeper and shallow aquifers are hydraulically connected, something which was observed during pumping test in well (D), when flow occurred from one aquifer to another. The shallow aquifer is not isolated from the surface and is vulnerable to contamination. Bicarbonate and calcium ions overall are dominant ions but Cl⁻ and Na⁺ ions are also present in high concentrations. Concentration of Cl⁻ of 70 mg·dm⁻³ in groundwater from Quaternary formation in the Rogóżno area is high, but not above the baseline range. Increased concentration of Cl⁻ and Na⁺ indicates that waters flowing into the well may be in contact with

waters of high salinity around the salt dome. The ion balance (Tab. 5) and values of hydrochemical indexes (Tab. 6) suggest that water in the well has characteristic features of both waters typical for the active recharge zone and of waters influenced by anthropological and geogenic factors. Interpretation of ionic ratios is difficult because of interference between anthropogenic contamination and geogenic contamination. The chemical composition and ionic ratio suggest that water in the well (E) is a combination of highly mineralized waters mixed with natural groundwater from the active recharge zone. High concentration of Cl⁻ (136 mg·dm⁻³), accompanied by high concentrations of Na⁺ (Tab. 5) suggests a geogenically saline water. In contrast to well (D), ion balance of the well water does not indicate that the Quaternary aquifer is in hydraulic contact with the first shallow aquifer, as it was in well (D). The environment in the aquifer is slightly reducing (Witczak et al. 2013). Values of the ionic ratio Na/Na+Cl (index 2) suggest a possible influence of the salt dome on the water chemistry (Tab. 6). The ionic ratio Na/Cl (index 1) informs about good isolation of the aquifer from the surface with only limited

contact with infiltration water. However, along with the presence of Na^+ , a risk of soil salinity is present (index 5). The ion composition of water sampled from wells (D) and (E), as well as hydrochemical indexes confirm the possibility of upward water flow (geogenically mineralized water) from deeper aquifers indicated in Figure 3 (Górecki 2015).

Well (B) is located right outside the northern border of the salt dome. The chemical analysis indicated that there are two ions dominating in the water: Cl^- and Na^+ (Tab. 5). The high concentration of these ions is characteristic for deep groundwater influenced by the leaching of rock salt or other evaporites (Macioszczyk & Dobrzyński 2002, Witczak et al. 2013). Indirect contact of water with saline rocks is also indicated by its high total mineralization. The water is slightly alkaline (Tab. 5) and has low value of oxidizing-reducing potential ($E_h = -518$ mV). Reducing the environment causes the minor participation of reduced concentrations of SO_4^{2-} which undergoes reductions and enriches water in H_2S (Macioszczyk & Dobrzyński 2002). Despite reducing conditions, the concentration of sulfates in water amounts to $110 \text{ mg}\cdot\text{dm}^{-3}$ which, in comparison with other water from the Upper Jurassic aquifer that were analyzed, is high. The dissolution of evaporites rich in this ion may provide a significant amount of sulfates. However, there is no increased concentration of K^+ or Mg^{2+} (Pazdro & Kozerski 1990) which are, frequently, related to the process. The slates confining the deeper aquifer could contribute to higher concentrations of SO_4^{2-} . The possibility of the salt dome influencing water chemistry is expressed in low values of ionic ratio HCO_3/Cl (index 4), characteristic for saline waters (Tab. 6). The ionic ratio $\text{Na}/\text{Na}+\text{Cl}$ (index 2) (about 0.5) informs us that the sodium in water comes from dissolution of halite. The well is currently used occasionally, only in the event of long drought periods to irrigate the surrounding area. A high concentration of Na^+ in comparison with other cations means the water would be unusable for irrigation (index 5). Any one using such water for irrigation may result in increased soil salinity (index 6). Upper Jurassic aquifers derived through the well (F) are located under a thick sequence of impermeable rocks. The water temperature in the outflow reaches 24.0°C (Tab. 5), which is classified as hypothermal waters

(Pazdro & Kozerski 1990). The conditions in the water are transitional, between oxidizing and reducing with unusually high pH (10.7). It is a rare occurrence that such an alkaline would be caused by geogenical factors (Witczak et al. 2013). There is no indication of any present contaminations, and possibly such a high pH is caused by naturally occurring conditions. The hydrochemical type of water and ionic ratios (Tab. 6) may confirm, as in case of the well (B), mixing of saline and natural groundwater. However, the ionic composition suggests that natural groundwater has a significantly higher impact in this mixture. It is indicated in confirmed with relatively low concentration of Cl^- and Na^+ , low water total mineralization and ionic ratios Na/Cl and $\text{Na}/\text{Na}+\text{Cl}$, respectively. The ionic ratio HCO_3/Cl is typical for waters of active recharge zone; it is also indicated by carbonate hardness (Pazdro & Kozerski 1990). Value of ratios ESP (index 5) and SAR (index 6) enables the water to be used for irrigation with no risk of increased salinity in the aquifer. Well (G) is located outside the eastern border of the salt dome. The low concentration of chlorides and sodium suggests that there is no contact with waters flowing over the salt dome (Tab. 5). Ratios Na/Cl and HCO_3/Cl inform us about the presence of waters in the active recharge zone (Tab. 6). It is also indicated by the carbonate hardness (Pazdro & Kozerski 1990). Lack of contamination flow is indicated by the ratio Ca/Mg . There are three dominant ions in the sample (H): Cl^- , Na^+ and Ca^{2+} (Tab. 5). The concentration of the chloride anion amounts to over $408 \text{ mg}\cdot\text{dm}^{-3}$, and sodium cation to over $206 \text{ mg}\cdot\text{dm}^{-3}$. The increased value of Ca^{2+} in the saline water may be caused by ion exchange. It occurs when high NaCl waters are in contact with carbonate rocks. This type of water is frequently present in deep hydrogeological structures (Pazdro & Kozerski 1990). Water in the outflow has a temperature of 24.0°C so, just like in the case of water from the well (F), which is classified as hypothermal waters. The total dissolved solids amounts to more than $1 \text{ g}\cdot\text{dm}^{-3}$, which classifies this water as having a relatively low mineral concentration (Pazdro & Kozerski 1990) in the poorly reductive environment (Witczak et al. 2013). This water flows from a neglected well through a narrow stream, into a nearby meadow and finally into a ditch. The surrounding area is endangered with the contamination of the soil and

the shallow aquifer due to improper protection of self-flowing saline waters. The ratio $\text{Na}/\text{Na}+\text{Cl}$ characterizes water as saline water which, according to the ratio Na/Cl , is very well isolated from the surface area (Tab. 6). The ratio HCO_3/Cl confirms the good isolation from surface water. The high total mineralization and content of chlorides and sodium causes the water to be unusable for irrigation (index 5). In the Rogóźno area, groundwater from the Upper Jurassic formation contact with a saline structure – a hydraulic barrier that also causes modifications in physico-chemical composition of the flowing water. The influence of salt dome on water from Upper Jurassic aquifer is found in the ion composition of groundwater derived from wells located on opposite sides. Groundwater derived from wells (F) and (G) do not indicate any contact with the salt dome. On the other side of the diapir, there is a high geological influence of saline rocks on physico-chemical composition of groundwater in wells (B) and (H).

There are four ions dominating the surface water in the pond (I): Ca^{2+} , Na^+ , HCO_3^- and

Cl^- (Tab. 5). High concentrations of Cl^- and Na^+ suggest the inflow of geogenically saline waters. A minimum presence of mineral forms of nitrogen and phosphorus confirms natural, instead of anthropological salinity (Górski 2001, Macioszczyk & Dobrzyński 2002, Witczak et al. 2013). Increased concentration of K^+ and Mg^{2+} may suggest the inflow of contamination from fertilizers. However, due to lack of any other signs of anthropopression, it is very likely that the source of these ions can be found in leaching of potassium-magnesium salts. Surface water in the pond may mix with saline water, which flows through a nearby unsealed exploration hole. A similar situation in groundwater is observed in wells (D), (E) and (F), respectively. According to archive documentation of the Marshal Office of Łódzkie Voivodeship, there had been a few piezometers near the pond in the past, characterized by very high concentration of chloride and sodium ions. The presence of not properly maintained well H-4 located close to the pond may cause the inflow of saline waters into the surface. A similar situation occurs in the outflow (H).

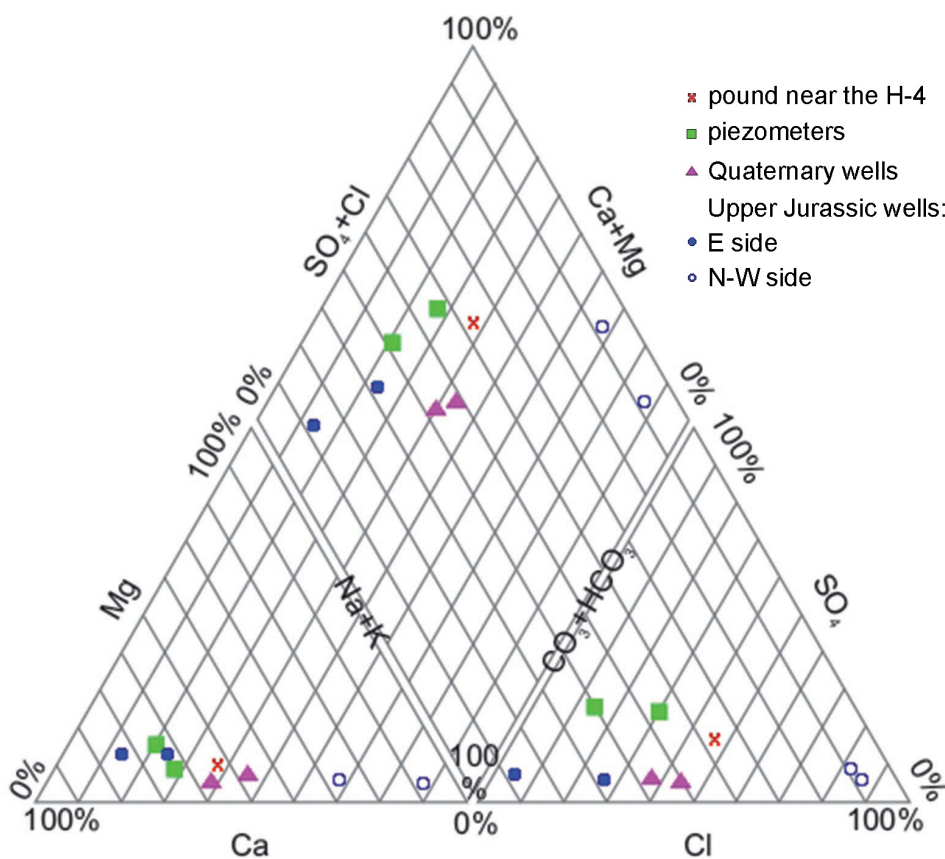
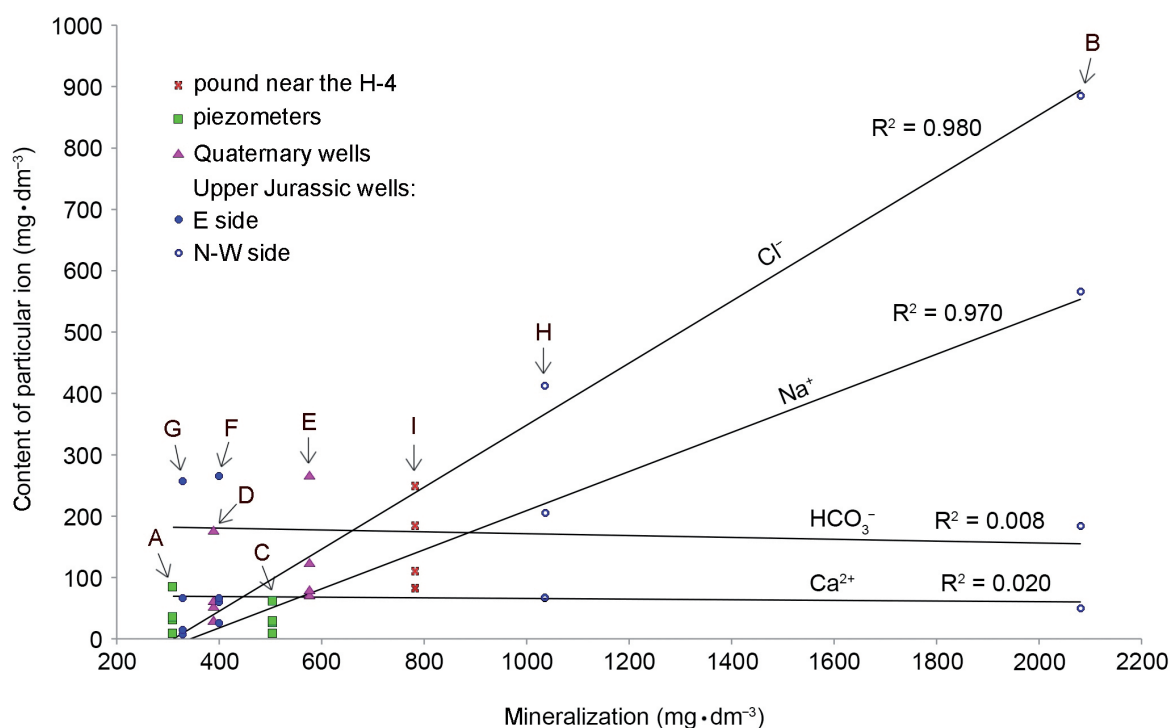


Fig. 9. Piper diagram with results of chemical analyses of groundwater and surface waters

The location of points on the Piper diagram (Fig. 9) confirms areas of presence of genetically different waters: natural, saline, transitional (natural and saline waters mixing with each other), as well as waters affected by anthropopression. In the case of water from the Upper Jurassic aquifer, the difference between natural water (F), (G) and saline water (B), (H) is very clear – the points are grouped in two zones located on the opposing sides of every chart (E side, N-W side). Wells from deep Quaternary formation (D), (E) are grouped between saline and natural water from Upper Jurassic aquifer which indicates

inflow of both natural and saline waters to them. The water in the pond (I) is also influenced by geogenical salinity – however, on a slightly greater scale than it is in the context of Quaternary wells. A similar example of salinization of surface waters was presented by Drwal & Borowiak (2000).

Using Ogilvy method (Kielczawa 2000), a chart showing the process of water mixing in selected wells and piezometers is shown in Figure 10. The rate of determination factor (R^2) close to unity signifies very high correlation between the mineralization of water and the content of ions.



Data coming from selected objects, due to reference of characterized ions to general mineralization, are arranged vertically. Each point of collection arranged vertically is marked with a symbol coming from Figure 2, Table 3 and Table 5.

Fig. 10. Ogilvy chart showing the mixing of water in the area of Rogóżno salt dome

CONCLUSIONS

The research and analysis of surface water and groundwater show the following:

1. Rogóżno saline structure is not completely isolated from surrounding waters. Tectonic, saline, glaciotectionic and karst processes influence the entire complicated system of groundwater circulation.
2. The salt dome is located along the groundwater flow direction of Upper Jurassic formation in the regional drainage zone. It is supported by the completely different ion composition of water on opposite sides of the diapir.
3. The pond (I) and wells (D) and (E) are located within the area of increased SEC values which surrounds the salt dome. A mixing of mineralized geogenical waters and waters from

shallow aquifers is present within Quaternary formation. These areas are influenced by saline water from around the salt dome.

4. The increased SEC in surface waters is present behind the northern border of the dome. The influence of the salt dome on surface water is expressed in high values of SEC and concentration of Cl^- and Na^+ in the Dezerta River.
5. The Moszczenica River is influenced by saline waters either through tributaries (the Dezerta River) or saline waters in ditches in the area of Władysławów and Lorenki.
6. Anthropogenic influence is reflected in anomalies of physico-chemical parameters of groundwater observed in piezometers.

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