

# Tectonically conditioned brine leakage into usable freshwater aquifers – implications for the quality of groundwater exploited in central Poland

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## ABSTRACT

Brine leakage areas, which are identical with zones of chloride ion content anomalies ( $\text{Cl}^- > 60 \text{ mg/dm}^3$ ) in usable aquifers, were mapped and examined on the basis of chemical and isotopic analyses. These zones are predominantly developed in tectonic conditions enabling the inflow of Mesozoic saline waters and brines into freshwater aquifers: 1) fault zones, 2) hydrogeological windows above salt anticlines and elevated tectonic blocks, 3) salt diapirs. The natural process of brine migration has been accelerated in some areas due to groundwater exploitation. Consequently, the decline of groundwater quality on many intakes has been reported, which is a result of the elevated content of chloride, Sodium and Ammonium ions.

## INTRODUCTION

This paper describes the phenomenon of brine leakage into freshwater usable aquifers and is associated with groundwater quality decline affecting intakes operating in central Poland. The studied area ( $28,000 \text{ km}^2$ ) corresponds to the region of well developed salt tectonics forms within the Permian-Mesozoic complex (Fig.1). In this area, groundwater is extracted from aquifers developed within Mesozoic calcareous and sandstones series as well as Paleogene, Neogene and Quaternary sand series.

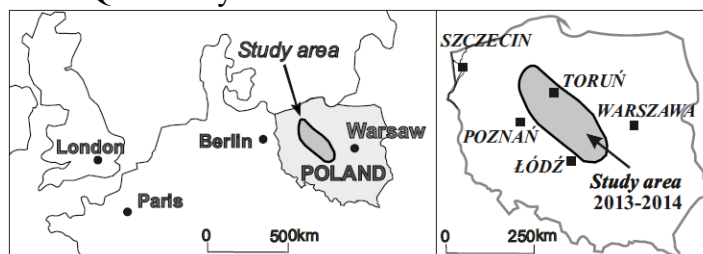


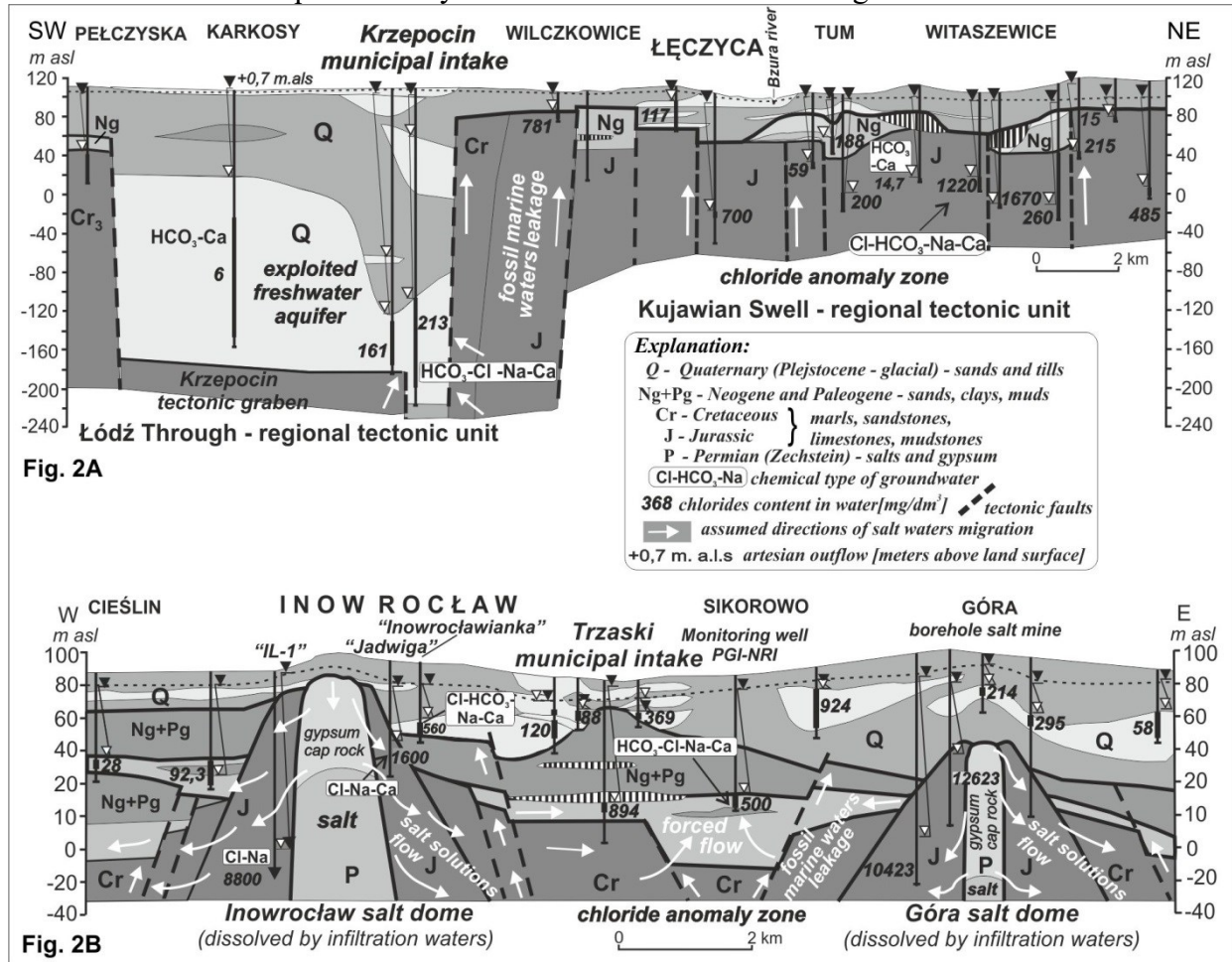
Figure 1. Location of the study area.

## METHODS

The preliminary stage of the study consisted in the mapping of the areas in which the brine leakage into freshwater aquifers is detectable. Such areas were named chloride anomaly zones, and were defined by groups of wells with the concentration of  $\text{Cl}^-$  ion in groundwater exceeding the value of  $60 \text{ mg/dm}^3$  – the upper limit of hydrogeochemical background. Spatial differentiation of water salinity in usable aquifers was documented with over 12,000 archival chemical analyses from the data bank of the Polish Geological Institute. Chemical data were verified for each intake. The results of analyses indicating that the elevated chlorides concentration in water originated due to anthropogenic pollution were rejected. The next stage of research was focused on specific chloride anomaly zones and on intakes affected by groundwater salinization. It included detailed chemical and isotopic ( $\delta^2\text{H}$ ,  $\delta^{18}\text{O}$ ) analyses of groundwater samples as well as groundwater table measurements.

## RESULTS & DISCUSSION

The hydrochemical and isotopic data allow for detecting at least 23 chloride anomaly zones in usable freshwater aquifers. They cover about 20% of the investigated area.



**Figure 2. Hydrogeological cross-sections through A) Łęczycza-Zychlin and B) Inowrocław chloride anomaly zones.**

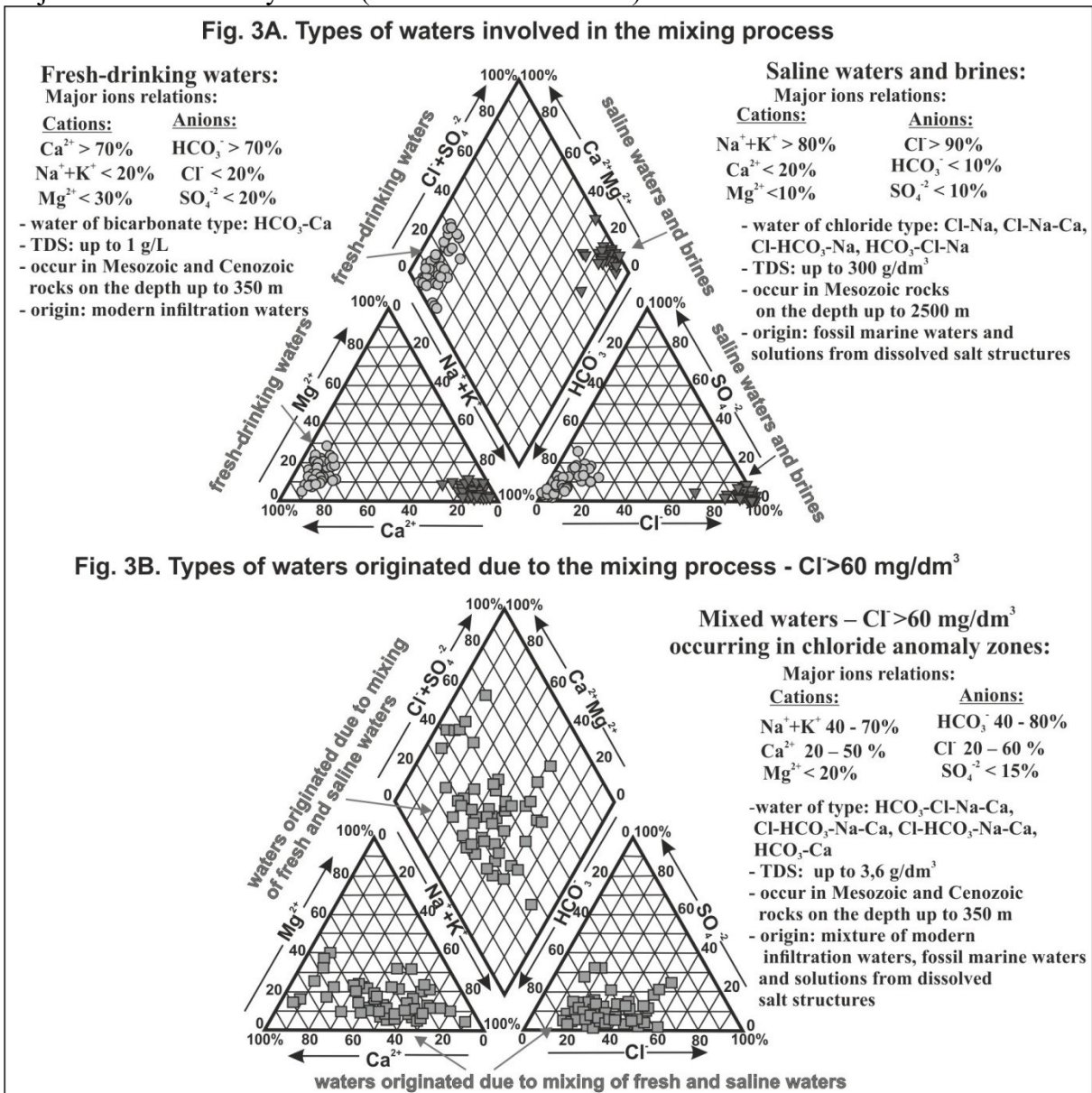
### *Tectonic determinants of chloride anomaly zones development within freshwater aquifers*

The correlation of hydrochemical, geophysical and drilling data confirmed that chloride anomalies have been predominantly developed in geologic situations, enabling the inflow of salt waters from deeper parts of Mesozoic complex into the useful aquifers. These are: 1) tectonic fault and fracture zones, especially those running along the borders of tectonic units (Fig.2A); 2) hydrogeological windows above uplifted crests of salt anticlines and elevated tectonic blocks; 3) mature salt diapirs currently being dissolved by infiltrating waters (Fig.2B). The conditions enabling the upward migration of salt waters through the tectonically produced pathways were confirmed with the archival results of pressure tests executed for Mesozoic brine-bearing aquifers in deep research boreholes (Kaczor 2006; Kaczor-Kurzawa 2017).

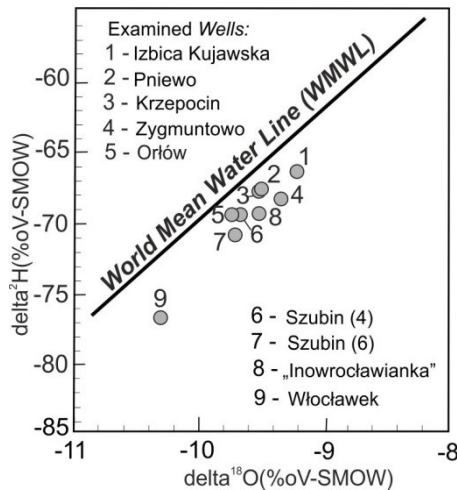
**Chemical and isotopic record of brine leakage into freshwater aquifers**

The upward migrating saline waters and brines have been mixing with fresh, drinking waters, which are exploited on groundwater intakes (Fig.3A). As a result of the mixing process, the groundwaters extracted on intakes situated within the detected chloride anomaly zones are converted to chloride type (Fig.3B). Their TDS value (up to 3.6 g/dm<sup>3</sup>) as well as ion relations are differentiated because of the various proportions between the mixed components of fresh and salt waters. In cation group, Natrium and Potassium ions prevail over Calcium. The composition of the anion group is dominated by bicarbonates ions, but the content of chloride ions changes from 20% to 60%. These waters are often characterized also by elevated K, Sr, B, Mg, Ba ion concentrations.

The leakage of saline waters, ‘older’ than modern infiltration waters (supposedly diluted Mesozoic brines), into freshwater aquifers, was proved by chemical and isotopic tests ( $\delta\text{H}$  and  $\delta\text{O}$ ) executed for groundwater samples from 9 working intakes (Fig.4) situated in 5 major chloride anomaly zones (Kaczor-Kurzawa 2017).



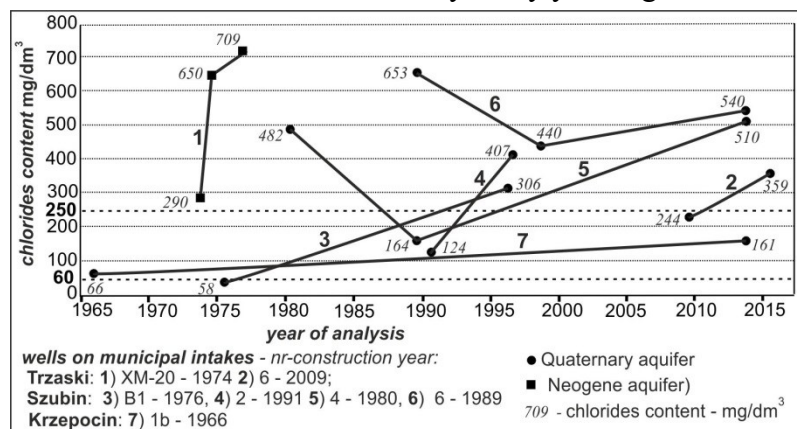
**Figure 3. Piper plots presenting chemical composition of waters involved and waters originated due to mixing process.**



**Figure 4. Graph of dependency between  $\delta^2\text{H}$  and  $\delta^{18}\text{O}$  in the analyzed waters compared to WMWL**

***Brine leakage implications for the quality of exploited groundwater***

Brine leakage is responsible for a significant decline in groundwater quality, which has been reported from numerous intakes working in the indicated chloride anomaly zones, due to the high concentration of chlorides ( $>250 \text{ mg/dm}^3$ ), Sodium ( $>200 \text{ mg/dm}^3$ ), Ammonium ( $> 0.5 \text{ mg/dm}^3$ ) ions, in some cases associated with elevated contents of sulfate ( $> 250 \text{ mg/dm}^3$ ) and Boron ( $> 1.0 \text{ mg/dm}^3$ ) ions. In general, chloride contents in groundwater increase with the depth, which reflects the inflow of saline waters from the deeper rock complexes. However, we can also observe the coexistence of fresh and salt waters with highly differentiated  $\text{Cl}^-$  ion contents, occurring at similar depths in neighboring wells (Fig.2A). This means that high chloride concentrations are related to a close presence of salt water migration routes, such as tectonic faults and fracture groupings in Mesozoic rocks. However, being located at a long distance from them, chloride concentrations decrease due to the dilution effected by infiltrating fresh waters. Therefore, only part of groundwater well populations within indicated anomaly zones display elevated chlorides concentrations. An attempt to estimate the scale of the geogenic salinization phenomenon included about 12,000 wells with documented chloride concentrations in groundwater. Only in about 300 (3%) of those wells did  $\text{Cl}^-$  ion content exceed the standard value ( $250 \text{ mg/dm}^3$ ) for drinking water. However, these calculations are primarily based on the data coming from the period of the wells being constructed and documented, usually many years ago.



**Figure 5. Graph of the temporal variability of chloride concentration in waters from selected intakes.**

In many cases, intake activity has been inducing and/or accelerating salt water flow towards the exploited aquifers, which caused a degradation of groundwater quality (Szubin and Trzaski intakes - Fig.2B, 5) and/or can lead to it in the near future (Krzepocin intake - Fig.5).

## CONCLUSIONS

The origin and location of the brine leakage areas, identical with chloride anomaly zones, are dependent on tectonic elements within the Permian-Mesozoic complex and on variations of their Cenozoic cover, the factors conditioning the inflow of Mesozoic salt waters into useful aquifers. In many cases, the  $\text{Cl}^-$  ion anomalies detected in groundwater of usable aquifers can be correlated with the spontaneous outflows of diluted brines, which created the natural  $\text{Cl}^-$  ion anomalies on the land surface. Their existence has been ascertained through soil research, and especially through botanical examinations describing the ecosystems of halophilous plants. The natural process of brine migration and leakage, occurring in the chloride anomaly zones, has been intensified by a long-term exploitation on groundwater municipal and industrial intakes. This can lead to a progressing salinization and degradation of groundwater quality, due to the elevated content of chlorides, Sodium, Ammonium and sulfates ions, exceeding the regulatory limits. That phenomenon affects dozens of currently working intakes, increasing water supply costs for numerous villages and towns.

## ACKNOWLEDGEMENTS

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