HYDROGEOCHEMICAL INVESTIGATION OF SEAWATER INTRUSION INTO CONFINED AQUIFER IN LIEPAJA CITY

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Introduction

Large scale pumping of groundwater starting from 1960.-ties has caused seawater intrusion into Upper Devonian Famenian multi aquifer (D3fm), particularly Muri – Zagare aquifer (D3mr-zg) in the Liepaja city area, and intrusion has developed towards water supply wells which are located inland to the south-east from Liepaja City. However, after collapse of USSR, water demand has declined and hence impact of seawater intrusion declines (Fig. 1). In this study attempt has been made to determine seawater intrusion rate and current hydrogeochemical conditions in Muru – Zagares confined aquifer by using data on chemical composition of groundwater samples, taken from exploration and monitoring wells.

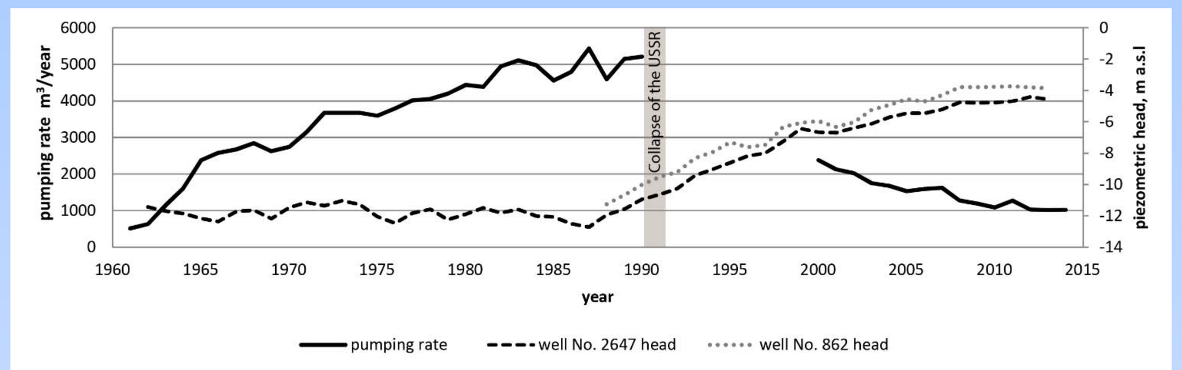

Fig. 1. Groundwater pumping rate and response to groundwater level

Site description

Liepaja city is third largest city in Latvia with 82'000 inhabitants and it is located in south-eastern part of the country, between the Baltic Sea and Liepajas lake (Fig. 2). Geology in study area consists mainly of Devonian sediments (thickness up to 800 meters) which consist of layers of sandstone, clay, silt and carbonate (mainly dolomite), and in some parts of gypsum.

Important groundwater source with good quality is Muru-Zagares aquifer which lies in depths of 10 to 120 m below surface and dippens south-eastwards (Fig. 3). At greater depth (250 – 410 m below surface) lies Burtnieku-Gaujas aquifer which hosts large quantity of groundwater, but with quality problems (high sulphate content). Almost everywhere in the area atop of Devonian sediments lies Quaternary low permeable till, except the bottom of the Baltic Sea where such confinig unit is not present.

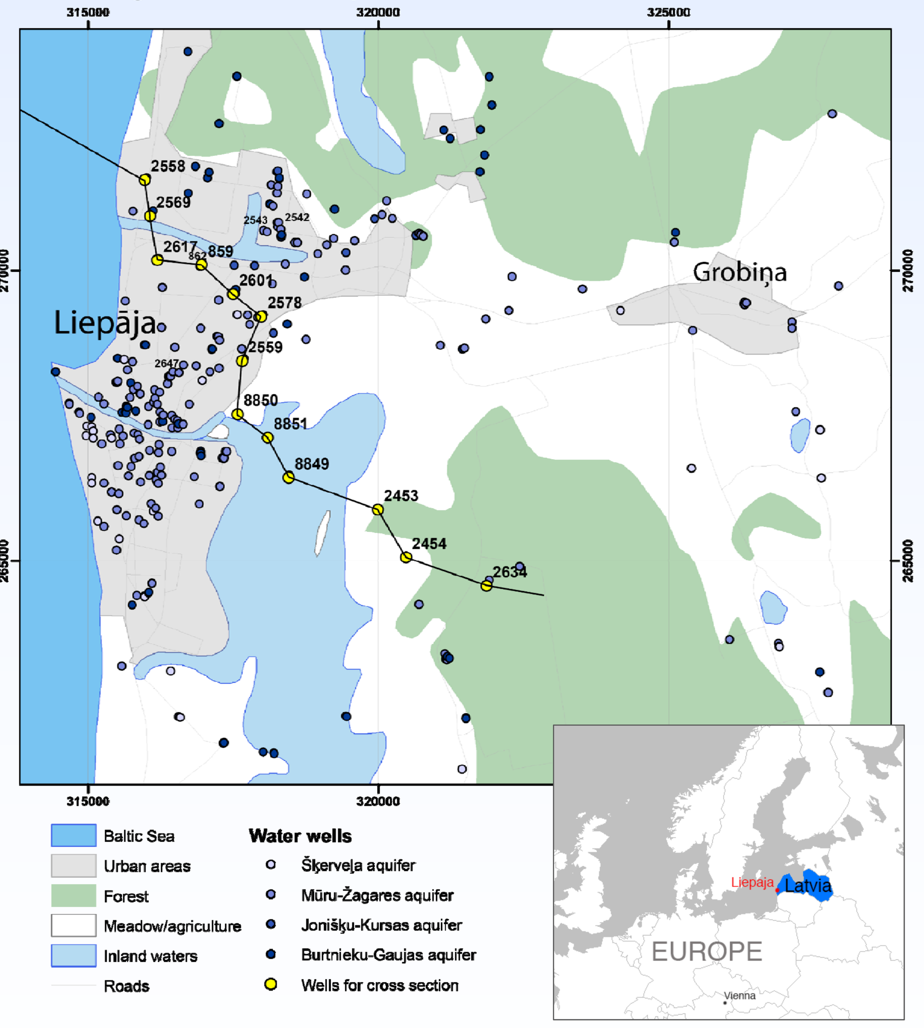

Fig. 2. Study area with locations of all water wells

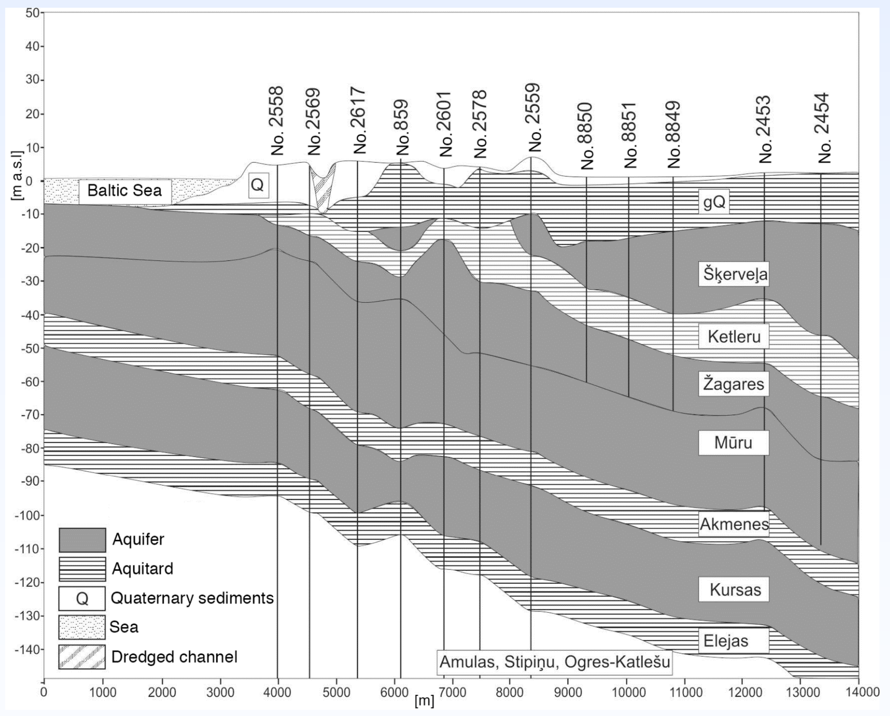

Fig. 3. Hydrogeological cross section

Materials and Methods

Dataset of major ions and trace elements were used acquired from monitoring wells, project wells and water supply wells dated from 1960.-ies to year 2014. Dataset includes 1296 groundwater samples in total from Muru-Zagares and Burtnieku-Gaujas aquifers, although further examination of data resulted in rejection of many samples (Fig. 4).

Groundwater hydrochemical groups were defined using hierarchical cluster analysis (HCA) and principal component analysis (PCA). These analyses require complete data matrix therefore they were performed only on the basis of full set of major ion concentrations. Prior PCA and HCA analysis dataset was pre-treated (Fig. 4).

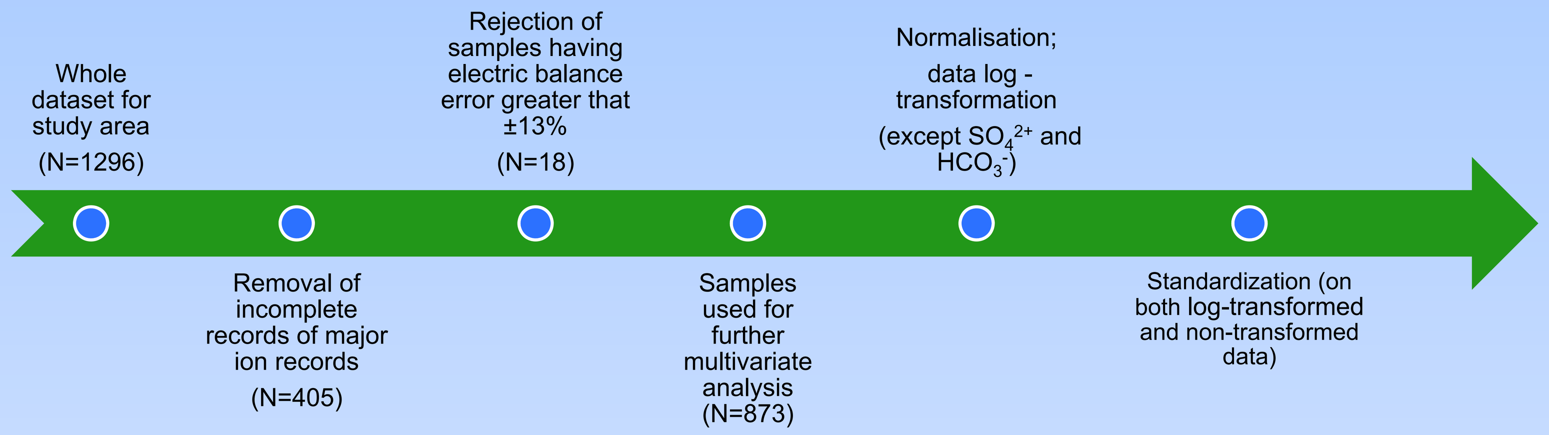

Fig. 4. Steps of data preparing for PCA and HCA analysis

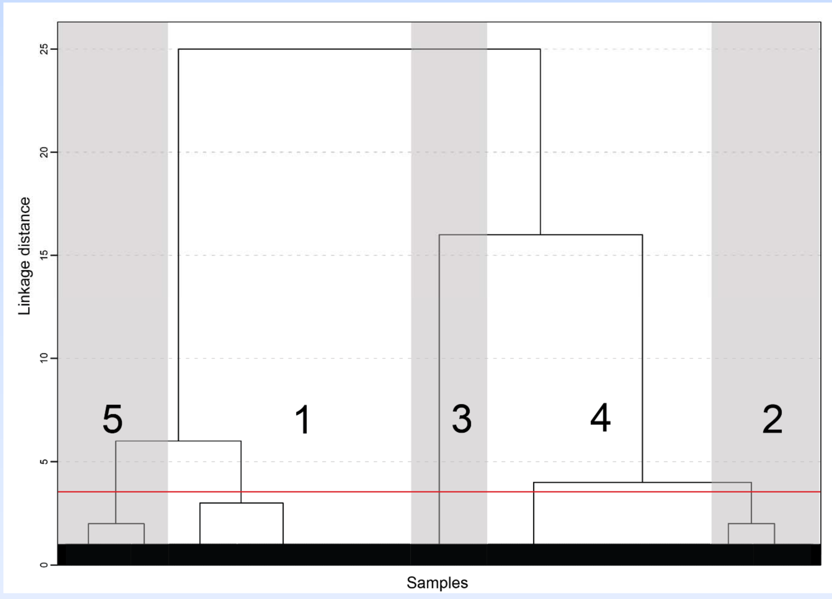

Fig. 5. HCA dendrogram showing division of groundwater samples.

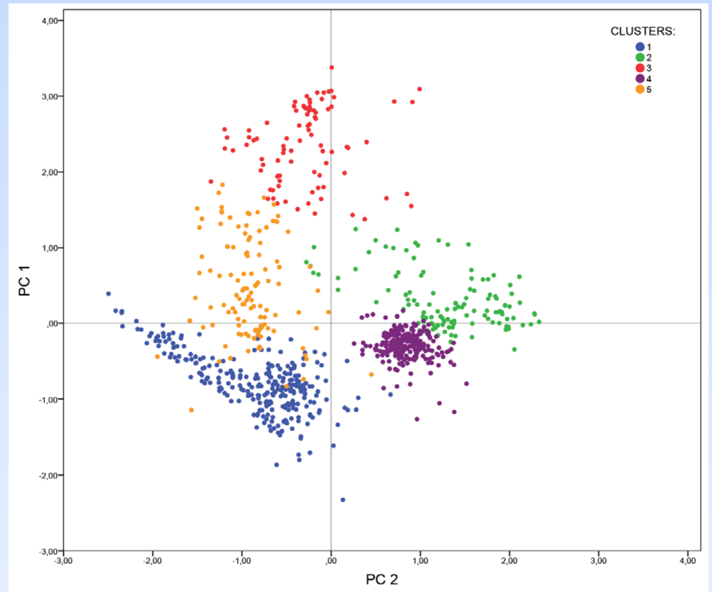

Fig. 6. Plot of loadings from PCA for the first and second PC

- Hierarchical cluster analysis was performed for grouping groundwater samples in a way that each group or cluster is homogeneous with respect to certain characteristics and distinct from other clusters regarding the same characteristics (Davis 2002). We used Euclidean distance as a similarity measure and Ward's method as a linkage method.
- Principal components was used as a dimension reduction technique (Davis, 2002); principal components (PC) were obtained through eigenanalysis of the correlation matrix and Varimax rotation was used.
- Saturation indicēs were calculated by using PHREEQC software (Parkhurst & Appelo 2013)
- Seawater content was calculated by: $$f_{sea} = \frac{m_{Cl^-,sample} - m_{Cl^-,fresh}}{m_{Cl^-,sea} - m_{Cl^-,fresh}}$$
- Theoretical groundwater composition for each sample was calculated based on seawater fraction in it: $m_{i,mix} = f_{sea} \times m_{i,sea} + (1 - f_{sea}) \times m_{i,fresh}$
- and diference Δm_i calculated as: $m_{i,sample} - m_{i,mix}$

which corresponds to ion concentrations involved in other processes than conservative mixing

References:
- Davis, J. 2002 Statistics and data analysis in geology, 3rd end. Wiley, New York.
- Parkhurst, D.L. & Appelo, C.A.J. 2013 Description of Input and Examples for PHREEQC Version 3- a Computer Program for Speciation, Batch-reaction, One-dimensional Transport, and Inverse Geochemical Calculations.

Results

Results from HCA analysis yielded 5 distinctive clusters (Fig. 5), each corresponding to specific groundwater characteristics. PCA analysis confirm distincted cluster groups (Fig. 6) as well as Piper diagram (Fig. 7). Cluster 1 corresponds to Muru-Zagares freshwater samples, cluster 3 represents samples from Muru-Zagares aquifer with high impact of saltwater, and cluster 5 plots in between cluster 1 and 3 showing minor signs of seawater intrusion. Clusters 2 and 4 corresponds to deep situated Burtnieku-Gaujas aquifer: cluser 2 represents considerably higher sulphate and calcium ion concentrations than cluster 4, in which Ca/HCO_3 ion ratio is generally lower (Fig. 10).

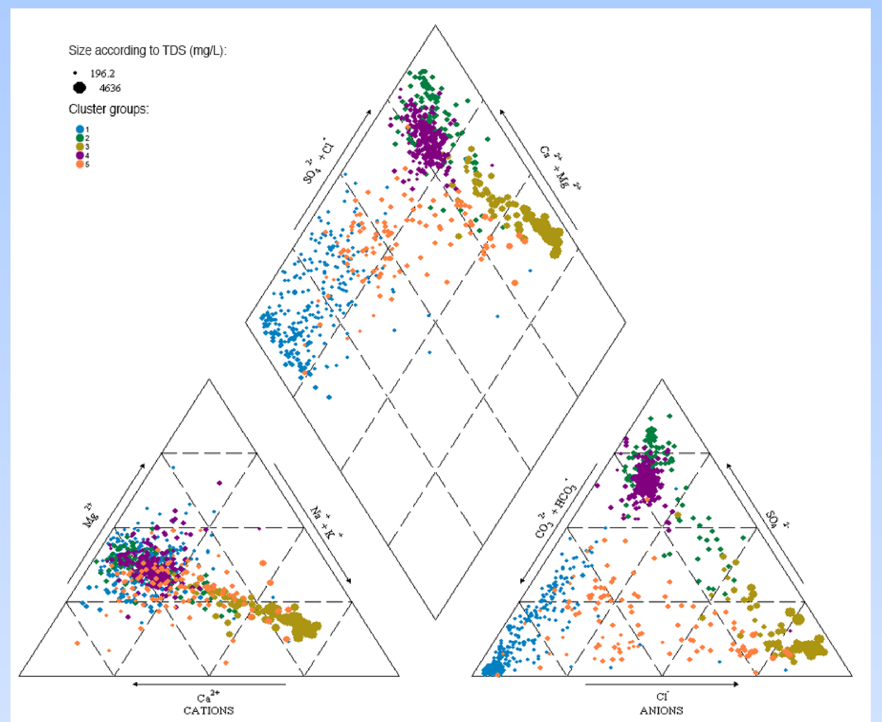

Fig. 7. Piper diagram for all samples

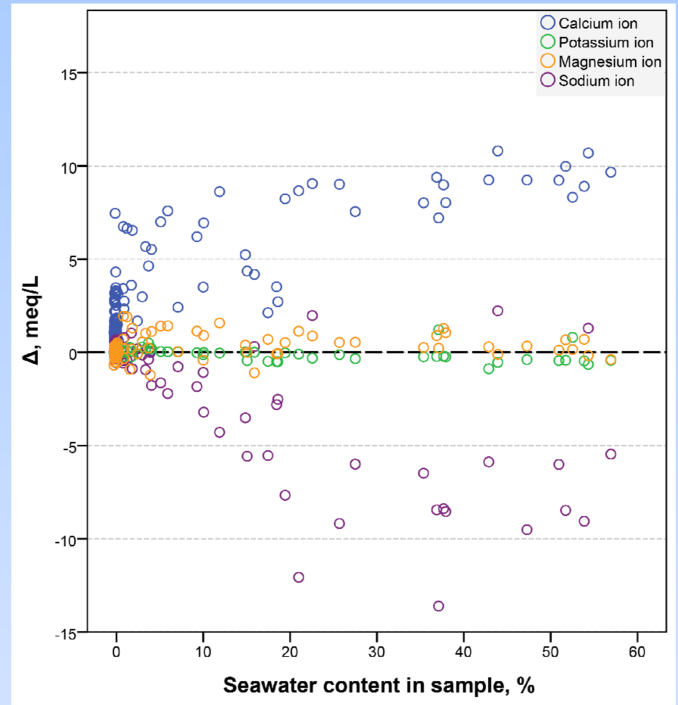

Fig. 8. Piper diagram for all samples

Muru-Zagares aquifer was investigated in more detail by conducting calculation of saturation indicēs (SI) and cation excess/deplition because of presence of seawater intrusion. Sodium showed great deplition and calcium considerable excess due to cation exchange process (Fig 8). At seawater content of 20% cation exchange process tends to stop advance (Fig 8) and calcite and dolomite saturation indices show particular sub-trend with elevated SI (Fig. 9).

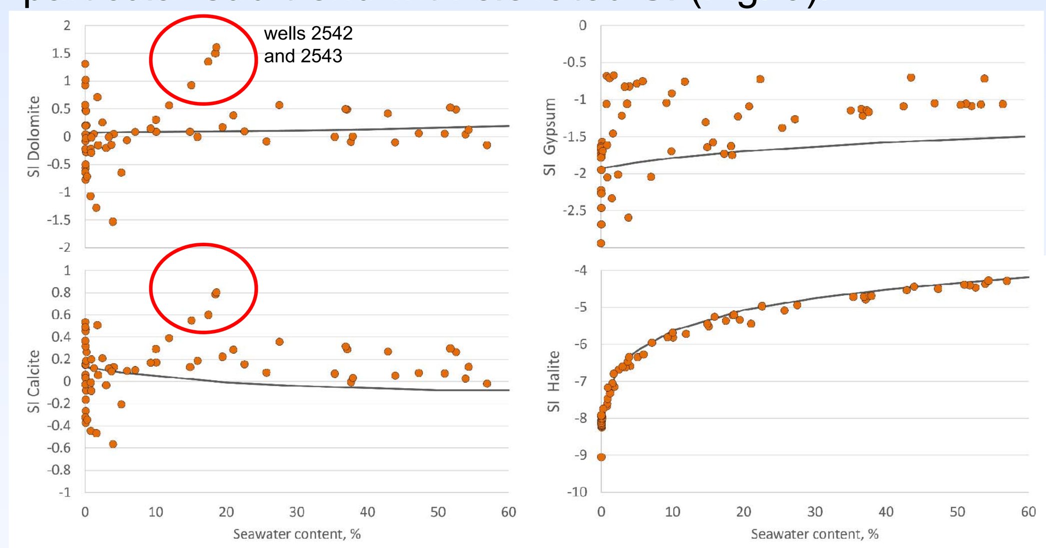

Fig. 9. Saturation indices for groundwater from Muru-Zagares aquifer, (gray line – calculated conservative seawater-freshwater mixing line)

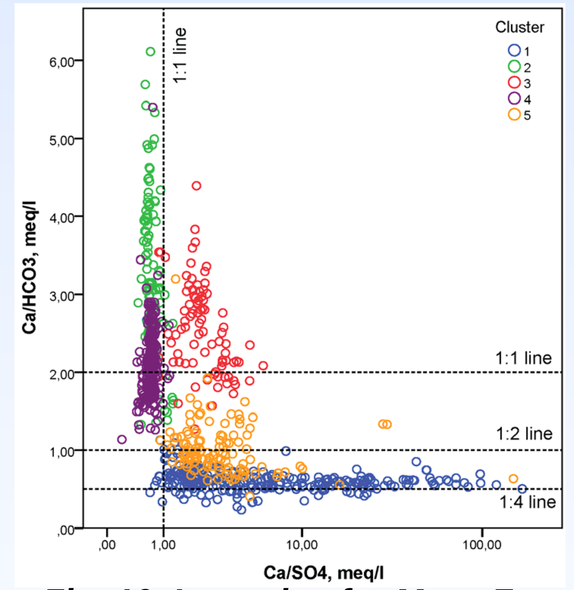

Fig. 10. Ion ratios for Muru-Zagares and Burtnieku-Gaujas aquifers

Conclusion

- HCA and PCA results can be applied to seawater intrusion study in Liepaja city as they can be used to distinguish saltwater influence rate and groundwater from other aquifers;
- Cation exchange process takes place in study area and equilibrium is achieved at 20% seawater content;
- Saturation indices show comparible good concordance with calculated SI except for two wells at northern part of Liepaja where, probably, refreshening occurs;
- Seawater content in wells located at the central part (well No.2647) can reach 57%

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