Does the fully automated groundwater management system lastingly influence the water quality in the 2nd and 20th district?

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Introduction

The 2nd and 20th metropolitan districts of Vienna (30 km² area) are enclosed between the Danube River and the Danube Canal, an old branch of the main river. The groundwater aquifer in this area is of importance as it is used periodically to feed the city water works. After the construction of the hydro power plant at Freudenau in Vienna, in order to maintain the groundwater regime in the 2nd and 20th districts unaltered a groundwater management system has been developed. An extensive doubled walled sealing system was constructed along the right river bank of the Danube which is 13 km long and extends up to 12- 40m depth. The groundwater flow is regulated with the help of withdrawing and recharging wells placed on either side of the walls. The direct infiltration of contaminants from the Danube is prevented through continuous control of the water quality and regular monitoring in an elaborate net of ground water wells (Dreher, 1991).

The developed fully automated groundwater management system will keep the groundwater flow in a nearly natural and predefined state. Further it will be possible to control the groundwater movement in order to avoid high water levels as well as to prevent excessive lowering of the groundwater table. The direct infiltration of contaminants from the Danube is prevented through continuous control of the water quality and regular monitoring in an elaborate net of ground water wells (190 groundwater wells and 20 surface water stations). During the period from 1992 – 2002, those monitoring sites were sampled regularly (quarterly, monthly or biweekly) and analysed for major constituents (standard methods), trace metals and organic micro pollutants.

After 10 years of full operation (1996 to 2006) changes of the affected ground- and surface water system can be pointed out by direct comparison of two periods (before (1992 – 1996) and after impoundment of the Danube River (1998 - 2002)) using statistical methods like direct correlation or cluster analysis (Forschung im Verbund- Band 96, 2005).

Methods

Within the scope of the quality hydrological monitoring program for the hydropower plant Freudenau 229 groundwater and 57 surface water stations were monitored regularly (quarterly, monthly or biweekly) for more than 100 different constituents using standard methods. For the period 1991 to 2002 more than 2 million single dates were recorded and have been analysed using various statistical methods. Main target was to figure out if changes in the water quality occur and in with extension alteration can be observed. In a first step the water quality data of all sampling sites were divided in a period before and after impoundment of the Danube. After evaluation the data using descriptive parameters like average, standard deviation, skewness or peakedness summaries per station were presented in form of tables and star plot diagrams.

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Similarities and connections between the parameters have been pointed out using a Sperman Correlation. As statistic test, significances of $\alpha = 0.001$ for highest significant, $\alpha = 0.01$ for high significant and $\alpha = 0.05$ for significant were used. Based on those statistical methods the whole data pool of analysed parameters can be limit from 133 parameters to 20 parameters. Structures in between that multidimensional database can be figured out using cluster analysis for objects (Stations) and variables (Parameters). Similarities within the data matrix are described as a tree diagram, where highest similarity have the smallest out branching and so these stations or parameters are located close to each other. Descriptive and statistical multivariate statistical methods, clustering and evaluation based on hydrological background information have been undertaken to differ between local and regional changes in the water matrix.

Results

20 parameters have been chosen to allow a detailed overview about possible changes of the matrix of examined water bodies. In general parameter can be divided into two groups, parameters which occur naturally based on the deposit of the underground determining the type of the water and into substances caused by autogenious or allogenic interferences that can reach concentrations up to toxic conditions. Analysis of pooled data of those 20 parameters of all groundwater stations results in two main clusters. The first cluster contains parameters like conductivity and hardness dominated parameters as the main cations and anions. Conductivity shows the highest similarities with the hardness and therefore with calcium and magnesium. Non carbonated hardness shows highest correlation with sulphate (coefficient of 0,94) whereas Sodium correlates with Chloride (coefficient of 0,9). The second cluster contains parameters like oxygen, water temperature, pH as well as Phosphate Potassium Nitrate and DOC (see figure 1).

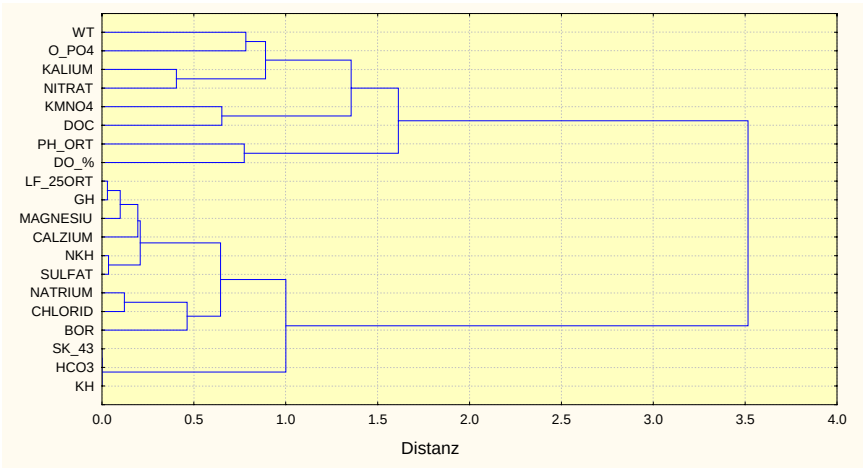


Figure 1: Cluster diagram of similarities of predefined parameter of all groundwater monitoring stations

The catchment area indicating parameters are: temperature, pH, conductivity (as unit for total dissolved Ions), hardness (as unit for occurrence of calcium, magnesium, strontium and barium-ions), non carbonated hardness (as a part of the total hardness deriving not from carbonate compounds but from sulphate-, chloride-, nitrate-, silicate- and phosphate-compounds), calcium (as main kation), magnesium, potassium (as indicator for erosion of fertilizer of humus poor ground during high rainfall) and bicarbonate (as unit for the buffer capacity of the water) (position 1-12 of the Star plot diagram). Second group summarizes parameters as indicator for anthropogenic origin like chloride (as indicator for waste water, thawing salt or potash fertilizer), nitrate (as indicator wash out of fertilizers as well as

decomposition and oxidation of organic and inorganic compounds), borate (as indicator for contaminations from enamel and glass industries), phosphate (as indicator for wash off of fertilizer, waste water containing washing power), dissolved oxygen and dissolved organic carbon (as indicator of anthropogenic activities (position 13-20). Figure 2 shows for the groundwater station 1930,541 the average concentration of the defined parameters as Star plot diagram for the periods before and after impoundment of the Danube. DOC and oxygen are increased while pH and conductivity are decreased. Major ions show a slight decrease in the concentration. This may indicate a close correspondence to the surface water quality of the Danube which has been infiltrated over abstraction and recharging wells along the Danube.

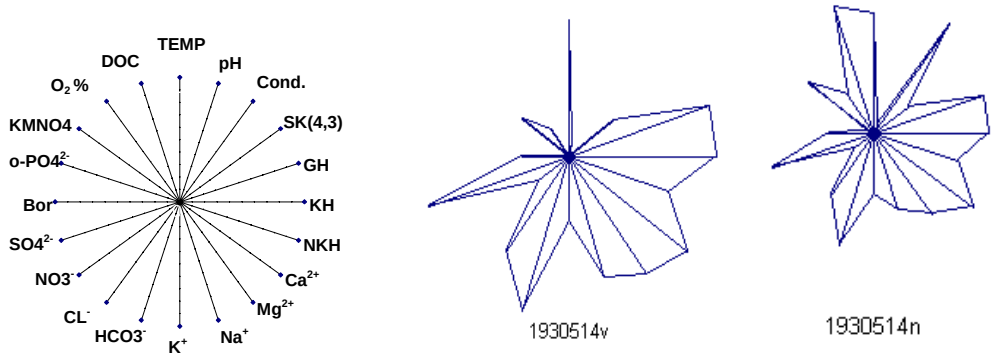
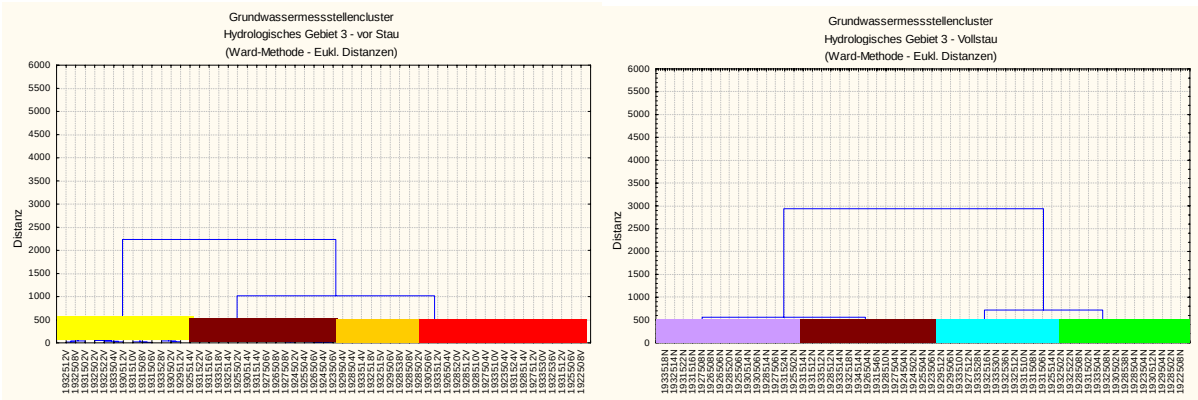


Figure 2: Star plot Visualization of average concentration of 20 different water quality data of the station 1930,514 for the period before (middle) and after (right star plot) impoundment of the Danube River

Cluster analyses of all groundwater stations within the 2nd and 20th districts for the two periods “before” and “after impoundment” based on the chemical data are shown in figure 3. For better visualization of regions with similar chemical matrixes of the aquifer, the subgroups of the station-clusters and the sampling sites have been coloured.



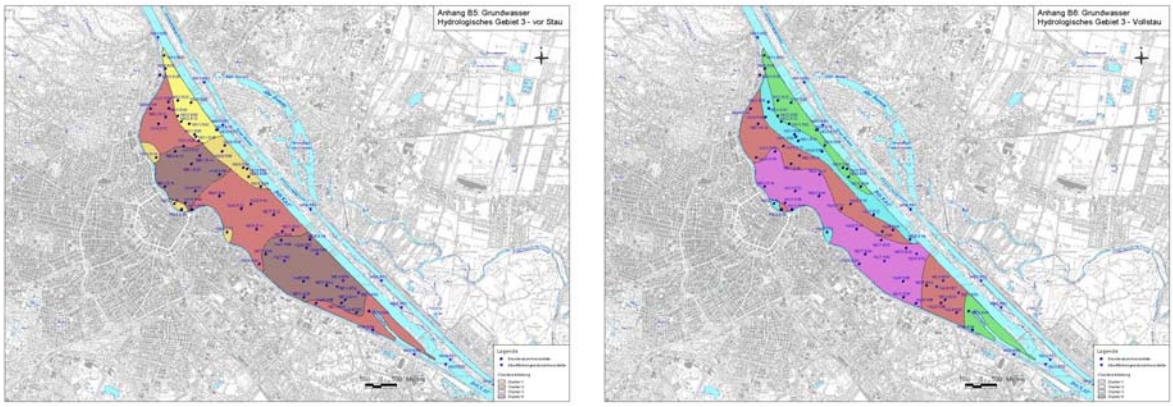


Figure 3: Cluster analyse of groundwater stations of the 2nd and 20th district (above) and visualization of the cluster-subgroups (distances < 500) for the periods before (left figures) and after (right figures) impoundment of the Danube River

Discussion

By constructing sealing wall along the river bank and regulating the groundwater flow with the help of withdrawing and recharging wells placed on either side of the wall, direct infiltration of contaminants from the Danube is prevented through continuous control of the water quality and regular monitoring in an elaborate net of ground water wells and on-line Stations. As the aquifer is used intermittently to feed the city water works, the maintenance and also improvement of ground water quality is an utmost necessity. Reoxygenation of the water before infiltration and an intensive water quality programme has been undertaken since 1996 (Dreher & Gunatilaka, 1996). A comparison of the water quality before and after impoundment (starting up of the groundwater management system) show that the chemical characters of the ground water changes gradually during the underground passage (Fig. 3). After 10 years of artificial recharge activity the average concentration of major constituents of groundwater monitoring stations in the whole area decreased in the aquifer. Calcium, magnesium and bicarbonate decreased between 5 and 15%, leading a decrease in hardness of 10%. Chloride, sulphate nitrate and sodium show the same effect which causes a reduction of conductivity between 5 and 15%. On the other hand dissolved oxygen concentration (DO), DOC or permanganate concentration increased between 20% (DO) and 6% (DOC). Sampling sites closer to the recharging wells are higher affected by the artificial infiltration than station in the hinterland. Stations with high similarities in the water matrix (Sub cluster) show stripy shapes parallel to the recharging wells along the right river bed of the Danube indicating an increase of constituents of ground water by passing the aquifer. After 10 years of operating the ground water management systems positive development of the water quality occurs through maintenances like pollution prevention in the aquifer, no infiltration of inorganic or organic pollutants, induced flushing of the aquifer and slightly improvement of the oxygen climate and reduction of inorganic strength and hardness.

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