Groundwater quality considerations related to artificial recharge to the aquifer of the Korinthos Prefecture, Greece

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Abstract Artificial recharge was employed in a preliminary study as a means to restore the aquifer system of the Korinthos Prefecture and it was concluded that this method can significantly contribute to groundwater quality improvement. Extreme care, however, must be taken as temporary quality deterioration may occur due to washout of the unsaturated zone. Boreholes and dug wells appear most vulnerable to pollution and damage compared to other methods of artificial recharge, since injected water directly reaches the saturated zone. Diluted air and suspended solids content are key parameters for the recharge rate sustainability. A direct relationship between aquifer matrix lithology and the aforementioned factors has been observed. Injection water should be of identical chemical characteristics to resident groundwater. Despite limitations in its application, artificial recharge with water of different hydrochemical characteristics to resident groundwater appeared to be a comparatively low cost, effective remedial measure for aquifer restoration.

Key words groundwater artificial recharge; groundwater quality improvement; high turbidity recharge water; Korinthos coastal plain; limited water resources

INTRODUCTION

A number of artificial recharge experiments were carried out in the northern coastal part of the Korinthos Prefecture, Greece, to investigate the applicability of the method and the associated problems, and to assess its efficiency for replenishing the aquifer system and improving the groundwater quality. The current study aims at presenting groundwater quality issues that need to be taken into consideration during the application of an artificial recharge programme.

Water needs in the area are principally covered by groundwater abstraction and additionally by surface water, mainly from the River Asopos. These are the only fresh water resources in the area. However water resources development has caused considerable groundwater quality deterioration (Daskalaki et al., 1998). Water demands have considerably increased over the last 15 years (Koumantakis et al., 1999b). Consequent overexploitation by the ever-increasing number of deep wells led to a
hydraulic head decline that triggered saline water intrusion. Salinization has become evident along some parts of the coastal sedimentary aquifer system. Groundwater quality deterioration is also being caused by the over-fertilization of crops and the use of abandoned shallow wells as septic tanks, as indicated by the reported increased nitrogen compound concentrations (Voudouris et al., 2000b). Surface water is also subject to quality deterioration due to illegal waste disposal from olive oil mills.

Groundwater artificial recharge has been considered as a promising remedial measure for the aquifer system, which is of paramount importance to the socio-economic development of the region. Its successful application requires good understanding of the geometry, the prevailing flow mechanisms and the evolution of the aquifer system. Despite problems in its application, artificial recharge appeared to offer a short- to long-term, comparatively low cost, effective remedial measure for aquifer restoration.

GEOLOGICAL AND HYDROGEOLOGICAL SETTING

The study area is situated in the northern coastal part of the Korinthos Prefecture and its geological structure is presented in Fig. 1. An aquifer system occurs in the recent basin deposits, which consist of unconsolidated materials: sands, pebbles, breccias and fine clay to silty sand sediments, characterized by a high degree of heterogeneity. The thickness of the basin deposits varies from 30 m to 70 m. Recent and older fluvio-torrential deposits originating from the streams and rivers that flow across the study area disrupt the lateral continuity of these sediments. Their thickness exceeds 100 m along the River Asopos (Koumantakis et al. 1999a).

In the south, Tyrrhenian deposits of coastal origin outcrop and their continuity is disrupted as a result of erosion. They consist of highly consolidated breccio-conglomerates, sand and gravel, with intermittent marl intercalations. It is believed that these deposits locally thicken to the north, underneath the recent unconsolidated sediments of the plain. Pliocene marl series occupy most of the hilly region further south of the study area and form the bedrock of the aquifer system (Panagopoulos et al., 1999).

Transmissivity and storage coefficient vary between $2 \times 10^1$ and $9 \times 10^2$ m$^2$ day$^{-1}$ and $0.1 \times 10^{-5}$ and $5 \times 10^{-2}$ respectively, as deduced from extensive pumping test analyses (Panagopoulos et al., 1999).

Recharge to the aquifer system originates from direct rainfall infiltration and riverbed infiltration. Lateral crossflow from the fluvio-torrential and also from the Tyrrhenian deposits across the southern edge of the basin, is essential to the system’s replenishment. Returns from flood irrigation, which is traditionally practiced in the region during springtime, also play a key role in the aquifer’s recharge. Mean annual temperature is 18.3°C, whilst average precipitation is 473 mm year$^{-1}$ and occurs mainly between late October and May, with sparse storm events during the summer months. Since the late 1980s, however, a change in the rainfall distribution pattern has occurred. Rainfall now occurs in fewer discrete events having a high intensity and short duration, resulting in higher runoff, lower recharge to the aquifer system and increased irrigation demands.
GROUNDWATER QUALITY

Study of the analysed groundwater samples showed that the average pH is 7.2, thus indicating a neutral environment. The average value of total dissolved solids (TDS) is high at 954 mg l\(^{-1}\) and exhibits significant local variation (standard deviation of the order of 550 mg l\(^{-1}\)). Total hardness (TH) in most of the samples exceeds 300 mg l\(^{-1}\) as CaCO\(_3\). Thus the groundwater is classified as very hard. All major ions exhibit wide variation in their concentrations across the study region but the dominant ions are Ca\(^{++}\) and HCO\(_3^-\).

Chloride (Cl\(^-\)) concentration shows a general increase downgradient to the north towards the coastline (Fig. 1), whereas it is lower along the main river courses and especially along the River Asopos. In addition to this trend, statistical analyses demonstrate a general increase of the chloride concentrations to the east (Voudouris \textit{et al.}, 2000a).

Nitrate is noticeable throughout the entire region, rendering most of the analysed waters unsuitable for human consumption, as concentrations far exceed 50 mg l\(^{-1}\) (EU Council, 1998). No specific pattern can be identified with regard to the nitrate concentration distribution. However high concentrations are observed in specific areas. Electrical conductivity varies between 550 and 4120 \(\mu\text{S cm}^{-1}\), and this is probably indicative of saline intrusion along the coastal areas of the studied system. It generally increases eastwards, as also indicated by statistical analysis of the hydrochemical data (Voudouris \textit{et al.}, 2000a), and reaches its peak at the Lecheo area (EC > 4000 \(\mu\text{S cm}^{-1}\)). The lowest values occur in the northwestern part of the region, where the River Asopos flows through the plain.
ARTIFICIAL RECHARGE EXPERIMENTS

A preliminary study was carried out in order to locate zones where artificial recharge would be most beneficial to the aquifer system, as well as to decide on the most suitable method of artificial recharge for each part of the region, taking into account the local conditions of land use, water use and the geometry of the lithological facies (Panagopoulos et al., 1999). The duration of the experiments ranged between 10 h and 23 days. Recharge water physiochemical parameters were continuously recorded throughout the entire duration of the experiments, as was groundwater in a network of monitoring points at various distances from the recharge well.

Eight experimental sites located in the western and central part of the study area were selected, although ion concentrations in that region are lower. In six of the experiments, large diameters dug wells (2-3 m), formerly used as production wells, were employed as recharge wells, whilst the remaining two were flooding field and flooding trench experiments.

In order to apply any artificial recharge method, water of adequate quantity and quality is required (Huisman & Olsthoorn, 1983). The River Asopos’ winter runoff was the main source of recharge water used in the experiments, and it was transferred to each site via the existing concrete lined irrigation canal network. The issues associated with using the selected source are the sparsity of surplus water between April and October (due to irrigation and climatic conditions), the chemical incompatibility between November and February (due to contaminant burden), and the unsuitability of the physical properties of the water. With respect to the latter, problems were associated with the high turbidity values and the high content of air bubbles. In particular, due to the morphology and lithology of the Asopos catchment, river water is rich in fine suspended particles. Recorded turbidity values were in the range 150–9000 NTU (nephelometric turbidity units). According to the American Society for Artificial Recharge of Groundwater (1998), turbidity of recharge water should not exceed 2–5 NTU and ideally should be less than 1 NTU. The river water used is also rich in dissolved air due to the flow velocity in the river and in the irrigation canals that were used to transfer water to the experimental sites.

Figure 2 demonstrates that water level changes in the vicinity of a recharge well are related to the supplied water quality. As can be seen, the increase on 4 April 1998 of suspended particle concentration is followed by an immediate groundwater level increase in the adjacent observation well. Water level rises as a result of reduction of the effective porosity and transmissivity in the aquifer zone surrounding the recharge well. This is due to well clogging caused by the suspended solids and dissolved air. An abrupt rise of water level was mainly observed during the afternoon and early evening of sunny and hot days. This was attributed to the snow thawing in the high ground of the catchment and the consequent increase of flow rates and the erosive capacity of the flowing water (Panagopoulos et al., 1999).

RESULTS AND CONCLUSIONS

Groundwater quality in the monitoring points adjacent to the recharge wells followed closely, as anticipated, the water chemistry of the recharge water. The experiments
Groundwater quality considerations related to artificial aquifer recharge

- Groundwater level (in)
- Recharge (low rate x 10⁻³ m³/t)
- Turbidity (NTU)

End of artificial recharge

30/3/98
1/4/98
3/4/98
6000
1000
5/4/98

Fig. 2 Water level fluctuation in the vicinity of the recharge well (1 m) in comparison with the turbidity and the flow rate of the recharge water.

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End of recharge period

Fig. 3 EC fluctuation at a monitoring point 15 m from one of the artificial recharge sites compared with the EC fluctuation of the recharge water.

demonstrated that artificial recharge with water of different hydrochemical composition resulted in quality improvement (up to 25–30%) of the resident groundwater. For example, Fig. 3 shows the EC graph plotted from a monitoring point 15 m distant from the recharge well.

In the early stages of the recharge period (Fig. 3), groundwater quality deteriorates as a result of the unsaturated zone washout induced by the water level increase due to the artificial recharge. The observed depression of the curve corresponds to the arrival
of the fresh recharge water at the monitoring point and denotes a considerable improvement in its quality, which is apparently maintained even after the end of the recharge period. This magnitude of improvement was short lived (1.5 months after the cessation of the experiments).

Wells appear most vulnerable to pollution and damage compared with other groundwater artificial recharge methods, since recharge water moves directly to the saturated zone, without passing through the unsaturated zone. In contrast, in flooding methods the recharge water is self-cleaned during its course from the unsaturated towards the saturated zone. However, extremely high land costs in the region restrict application of this method. In addition, the success of flooding methods relies on the existence of continuously permeable sediments, from the soil surface to the saturated zone, which is not the case in the study area.

The experiments demonstrated that in order to maintain the transmissive capacity of the recharge wells, cycles of artificial recharge, pumping, and reapplication of artificial recharge should be implemented in order to remove the fine particles and trapped air bubbles that clog the well. The whole approach provides an inexpensive method of groundwater quality improvement that requires no prior treatment of the recharge water and is suitable for areas with limited resources. No spectacular results are anticipated, but immediate application can be programmed since no specialized engineering works are required, hence making the method suitable for crisis situations.

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