Preliminary signals of groundwater contamination of stressed coastal aquifers: the case of the Eastern Mediterranean groundwater basins
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Abstract

Coastal areas are in general characterised by high on-going levels of population growth and domestic water demand. Major sources of pollution are urbanisation and overpumpage of aquifers. The result is an increase in salinity and pollution from sea water intrusion and other high-salinity sources, and from anthropomorphic percolation from ground surface to the water table. The purpose of this study is to delineate guidelines to identify preliminary signals of groundwater salinisation in areas under high land-use contamination pressure, and under impact of stress-management.

The study is based on analyses of groundwater chlorographs and nitrographs of wells located along the Israel and the Gaza Strip Coastal aquifers, in inland areas with high anthropogenic activities, as well as in areas where groundwater under stress-management is influenced by sea water intrusion. In these areas, Cl\(^{-}\) graphs indicate that after some years of monotonous behaviour corresponding to a steady-state flow regime, a fluctuation rate of 3 to 5 years sets in previous to the onset of final assault of groundwater salinisation. This intermediate stage can be considered an early-warning signal, occurring most clearly when the contaminant source is as massive as sea water. In the other cases, the amplitude of the fluctuation stage also depends upon properties and magnitude of contaminants, the flow regime, and aquifer matrix characteristics. Such observations enable the undertaking of early operational activities needed to rectify adverse groundwater quality trends, as well as planning and choosing adequate aquifer remedial measures. Such graphs can therefore be utilised as a tool for groundwater quality monitoring and control.
Introduction

Long term overpumpage of Coastal aquifers leads to a stressed situation which appears as decline in groundwater levels, along with alteration of the natural circulation direction of groundwater flow. This reduces the normal washing of salts into the sea, and increases inland aquifer salt and pollutant concentrations (Fig. 1). While contamination effects increase significantly in the aquifer, self-restoration capacity diminishes, e.g. USEPA\textsuperscript{12}, Travis & Doty\textsuperscript{11}. Therefore, the state of stress of groundwater resources should be a concern for persons and organisations tackling water issues around the world with the objective of sustainable aquifer management, e.g. Ableson\textsuperscript{1}, Davis\textsuperscript{2}. For this purpose, the aquifer’s eco-hydrogeological characteristics must be understood, including various salt and pollutant trends, in order to formulate a framework within which effective decisions can be taken.

The central objective of this study is therefore to determine guidelines which can isolate preliminary aquifer signals preceding the initial assault of salinisation. Such guidelines are proposed here, involving observation of chloride and nitrate curves of groundwater under stress-management for the coastal phreatic aquifers of Israel and Gaza Strip.

![Figure 1. Schematic presentation of the process of groundwater contamination in an aquifer](image-url)
2 Methodology

This study investigates the pattern of groundwater contaminant changes in coastal aquifer areas under stress-management, involving such concepts as:

1. Choice of parameters which are routinely reported and can represent salinisation and/or pollution processes in groundwater.
2. Utilisation of data which include a period of time preceding the onset of significant adverse effects from anthropogenic activity upon groundwater quality.
3. Sampling from pumping wells located in areas where there is a high probability of sea-water intrusion, as well as inland areas (more than 2000m from the seashore), where anthropogenic activities and groundwater management contribute relative stress.
4. Identification of contamination impact upon groundwater: a.) by use of vertical profiles of groundwater chemical parameters to assess land-usage effects; and b.) by analysing groundwater quality curves of specific wells to detect impact of groundwater stress-management involving such major sources of salinization as sea water and brines upon groundwater aquifer quality.
5. Utilisation of laboratory findings to gain a better understanding of groundwater quality and aquifer change-rates

The parameters used in this study are chlorides and nitrates. Chlorides, as conservative, non-reactive constituents within aquifer matrix material, can be used as good tracers to follow the processes of groundwater salinisation, especially from sea water and brines e.g. White, Konikow & Rodriguez. Nitrates, although not good tracer parameters, may be utilised to identify anthropogenic pollution in wells.

3 Hydrogeology of the study area

The study area is located along about 120 km of the Mediterranean coast, and between 5 to 15 km inland (Fig. 2), involving a highly populated area, with intensive levels of industrial, agricultural, and other land-use activities. The Israel and the Gaza Strip Coastal aquifers are involved. These are composed of sand, sandstone, and silt, interbedded with clay lenses, containing several water producing zones e.g. Tolmach.
The aquifers are recharged by: rainfall, water percolating from agricultural, industrial, and domestic sources, and along Israel's coast, by artificial recharge. These aquifers have been over-exploited, most specifically the Gaza Strip aquifer. The hydrological situation is characterised there by a decline in groundwater levels of more than 10 centimetres per year. Close to the seashore, this results in an increase in groundwater salinity due to sea water and other salt water intrusion. Inland, this results in a significant increase in groundwater contaminants e.g. Melloul & Gilad, Melloul & Collin, Hydrological Service Situation Report.

These Coastal aquifers are used here to characterise a general pattern to be expected upon onset of groundwater quality deterioration within such phreatic coastal aquifer conditions. All data involved in this work have been collected by the Hydrological Service of Israel (IHS) for periods between 1952 to 1992.

Figure 2. Location map of the Coastal aquifer of Israel and Gaza Strip Authority
4 Observation of chlorographs and nitrographs in groundwater along the eastern Mediterranean coastal ground water basins

4.1 Depth profile in areas under stress from land-use and environment

Figures 3 and 4 respectively represent vertical profiles of groundwater chloride and nitrate levels, based upon averaged values of around 50 wells located in northern and central portions of the Israel Coastal aquifer, at a distance of 2 to 7 km from sea (Fig. 2). Figures 3 and 4 indicate that between 1967 and 1985, shallow layers, at depths to 40 meters below sea level (b.s.l.) present larger fluctuations, highest levels of groundwater salinity and pollution and rates of salinisation and pollution. Deeper layers (depths greater than 80 meter b.s.l.) yield groundwater quality fluctuations with smoother curves. For all layers, nitrate fluctuation changes with depth are more significant than those for Cl⁻. Thus, for these aquifers, sources of pollution are mainly from the ground surface, where the phreatic aquifer is overlayed by high levels of heavy-contaminant land-use activity. These data also testify to the fact that the closer groundwater is to contaminant sources, the larger the fluctuations.

4.2 Observation of chlorographs and nitrographs in specific wells located near sea shore

Groundwater quality deterioration behaviour is more significantly illustrated by wells located in proximity to the sea shore. Figures 5 and 6 present respectively nitrographs and chlorographs of wells S1, S2, S4, S5, S6, S10, S11, and S12. These wells are located along the Coastal aquifer of Israel and the Gaza Strip (Well S6), up to 1500 m from the sea shore, and in areas where sea-water intrusion can be expected.

Figure 5 represents nitrate data behaviour between 1968 and 1994 along the seashore of Israel’s Coastal aquifer. There, nitrates are at low levels and show no significant increase. However, when
considering the Gaza Strip’s Coastal aquifer, values of NO₃ in some wells exceed 100mg/l e.g. Melloul & Collin⁷.

Figure 6 represents chlorographs, mostly evidencing three different portions or stages. Stage a entails initial chloride concentration data characterised by the lowest levels and smallest fluctuations. Stage b is characterised by more significant fluctuations, lasting three to five years. In this stage, Cl⁻ values are still at low levels, and fluctuate from 50 to 100 % around an approximate mean value. Stage c commences only when Cl⁻ values begin to increase rapidly at rates higher than 20 mg/l Cl⁻ per year. The figure indicates that despite varied distances between wells (Fig. 2), chlorographs have similar behaviour. This phenomena also appears in Suleiman⁹ as regards groundwater salinity in the Suani wellfield of the Coastal Plain aquifer along the eastern portion of the Mediterranean sea at Tripoli, Libya.

From Figure 6 one notes that for certain wells, the fluctuation stage is not distinct. This is due to significant differences in Cl⁻ concentrations between the initial and final portion of these graphs (Cl⁻ values varying from 50 to around 2500 mg/L). Additionally, one notes that in some cases, as in the Gaza Strip well S6, the fluctuation stage of the chlorograph indicates relatively higher Cl⁻ levels. This can be explained by anthropogenic stress and polluted conditions in this aquifer e.g. Melloul & Collin⁷. Laboratory findings of Goldenberg et al.⁸,⁹ explain that the magnitude of such fluctuations may be related to lithologic matrix changes, aquifer heterogeneity, flow characteristics, and contaminant properties.

5 Discussion

This study shows by means of observation graphs the response of an aquifer to a variety of eco-hydrological stress scenarios. From initial stages of abstraction, when management is under a steady state regime Cl⁻ and NO₃ hydrograph curves respond to contaminant input as continuous and monotonous lines (Fig. 1).

With low levels of contaminants but with increased groundwater management and environment stress, groundwater quality changes are related to the significance of contamination sources and to local groundwater gradients produced (Fig. 1). It does appear that the closer the phreatic aquifer water table is to an intensive land-use
activity area, the stronger the fluctuations may be, their values exceeding ambient fresh groundwater background values.

In inland areas, where contamination comes from the ground surface and there is a non-steady-state flow regime, Cl\textsuperscript{-} as well as NO\textsubscript{3} graphs exhibit fluctuations (Fig. 1), with a continuous increasing trend of contamination of around 1 to 10 mg/l per year. Near the seashore, as illustrated by Fig. 6, the contamination process more clearly involves three stages. Stage a is characterised by a steady-state regime in which groundwater chemical concentration levels and trends are relatively stable and low. In stage b Cl\textsuperscript{-} graph curves show significant fluctuations which can last between 3 to 5 years before the onset of a sharp increase in groundwater salinity. This stage can be augmented because of aquifer heterogeneity, flow domain, contaminant properties, as well as anthropogenic contamination sources, as seen in the case of Gaza well S6. Fluctuation stage characteristics can be a guide to identify the type and order of magnitude of contamination sources influencing groundwater in these areas, before the water arrives at stage c, where salinity concentration increases sharply until groundwater well production is threatened. This last stage appears more significantly in the presence of a major contaminant source, such as sea water intrusion into the aquifer. Stages b and c are, in fact, related to the contamination process of groundwater, stage b being the intermediate stage at which is desirable to remedy the situation as soon as possible before further alteration of groundwater takes place. Utilisation of nitrates has been utilised in this case mostly to demonstrate impact of manure and domestic pollution upon groundwater, as well as to indicate the degree of anthropogenic load, particularly along the seashore.

6 Conclusions

Analysis of chlorographs and nitrographs of groundwater from areas under different stressed eco-hydrological scenarios leads to the conclusion that curve characteristics in the fluctuation portion of a graph can indicate type and magnitude of contaminants affecting groundwater. It is important to focus on the fluctuation stage in order to take appropriate early measures to rectify adverse groundwater quality trends and promote sustainability management of the water resource. Graphic curve observations may be utilised
as a tool to detect preliminary signals of groundwater quality degradation, and gain fuller understanding of conceptual models of aquifer contamination.

Figure 3. Vertical depth profiles of chlorides in the Israel Coastal aquifer.

Figure 4. Vertical depth profiles of nitrates in the Israel Coastal aquifer.
Figure 5. Nitrographs of groundwater wells near the sea shore of Israel’s Coastal aquifer.

Figure 6. Chlorographs of groundwater wells near the sea shore along the Israel and Gaza Strip Coastal aquifer.
References