

# THE VULNERABILITY OF GROUNDWATER TO POLLUTION AND STRATEGIES FOR ITS PROTECTION UNDER THE FARMING CONDITIONS IN THE MEDITERRANEAN COUNTRIES

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## THE GROUNDWATER ENVIRONMENT

The groundwater environment may be considered as the *output* from the surface or the soil zone.

This mainly applies to shallow groundwater. The main sources of groundwater are precipitation and subsurface flow.

From surface to subsurface, the groundwater quality is affected by various geochemical processes which modify its chemical contents.

Aquifers have specific characteristics that distinguish them from other water bodies: (i) they can help in removing suspended solids and disease-causing organisms; (ii) they can store water in quantities exceeding those which are or conceivably could be stored in all natural and artificial surface-water bodies; (iii) they can regulate the water temperature and its chemical quality; (iv) they transport water from areas of recharge to areas of need; and (v) they slow-down the natural discharge of water to the surface.

As such, aquifers can be utilized as strategic storage reservoirs for water to make up the bulk of the dry-weather flow of streams. Groundwater pollution is a function of various factors and processes that can be classified as internal and external.

The geochemical processes and the vulnerability of groundwater to pollution are the most important internal factors; while human activities are the most effective external factors.

### Natural geochemical processes

Natural geochemical reactions may impart adverse properties to groundwater. Important geochemical processes, in terms of their role in controlling and modifying groundwater composition are discussed in the

### ABSTRACT

Groundwater forms one component of the hydrological cycle on earth. As such, it is affected by and affects the other water components. As it is understood from its name, groundwater is generally not totally exposed to the surface like it is the case with surface water. This should make groundwater less vulnerable to pollution than surface water. However, once polluted, it is very difficult to bring groundwater quality to its original condition.

### RÉSUMÉ

*Les eaux souterraines font partie du cycle hydrologique sur la terre. Pour cela, elles subissent et exercent un effet sur les autres composantes hydriques. Ainsi que le nom l'indique, les eaux souterraines, différemment des eaux de surface, ne sont pas du tout exposées à la surface. Ceci rendrait les eaux de nappes moins vulnérables à la pollution par rapport aux eaux de surface. Toutefois, une fois polluées, il est très difficile de ramener la qualité de l'eau souterraine à sa condition originelle.*

following paragraphs.

*Acid attenuation and mineral dissolution.* The main process of groundwater mineralization takes place by acid-base reaction in the top few meters of the earth's crust. The microbiological activity of the soil may increase the CO<sub>2</sub> concentration, which is of fundamental importance in determining the extent of reaction as well as reaction pathways in the groundwater system.

The nature of the geochemical reactions depend also upon whether the system remains open (phreat-

ic aquifers) or closed (confined aquifers) with respect to the atmospheric/soil CO<sub>2</sub>. Reactions with CO<sub>2</sub> are the most important in determining the groundwater quality in both carbonate and non-carbonate aquifers (Appelo & Postma, 1993).

The common features is an increase in pH and production of HCO<sub>3</sub><sup>-</sup>. Moreover, silical and another secondary mineral are produced during the weathering reactions of silicate minerals. Reactions of the silicate minerals also lead to a build up of Si.

*Redox reactions.* Under natural conditions, groundwater undergoes redox changes moving along flow lines (Champ et al, 1979).

The most important long-term process is the consumption of oxygen, as it reacts with organic matters and/or Fe<sup>2+</sup> released from dissolution of impure carbons, silicates, or sulphide.

*Salinity changes.* Chloride in shallow groundwater is derived almost exclusively from the atmosphere. Natural increase in groundwater salinity may arise from several sources: (i) release of ancient saline formation waters of marine or non-marine origin; (ii) entrainment of saline water from a saline/fresh water interface which relates usually to the depth of active groundwater circulation; (iii) dissolution of evaporate minerals; (iv) entrainment of recent sea water; and (v) prolonged weathering of biotic and other igneous minerals.

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## The vulnerability concept

The vulnerability of groundwater to pollution is an important factor in modifying the pollution load in groundwater. Vulnerability is an intrinsic property of a groundwater system that depends on the sensitivity of that system to human and/or natural impacts (IAH, 1994). It depends essentially on the leaching capacity of the upper soils. Other definitions are also common.

*Drastic system.* A standardized rating system evaluating groundwater contamination potential of selected hydrogeological settings, based on: (i) Depth to water table; (ii) net Recharge; (iii) Aquifer media; (iv) Soil media; (v) Topography; (vi) Impact of unsaturated zone; and (vii) hydraulic Conductivity of aquifer.

If both concepts are combined, the best way to illustrate the groundwater vulnerability to pollution is by developing groundwater vulnerability maps. Groundwater vulnerability maps are the basis for:

- (i) regulatory and decision making purposes;
- (ii) environmentally-sound decisions regarding groundwater protection and land use;
- (iii) the design of monitoring networks;
- (iv) evaluation of non-point groundwater contamination; and
- (v) the information of planners, managers, decision and policy-makers, and public about groundwater protection, risk and prevention of contamination.

## Human activities

Human activities are diverse. If we consider only those activities related to farming, the most important with respect to groundwater pollution are the irrigation, pesticide and fertilizer application, farm animal wastes, natural leaching, overpumping, and sea water intrusion. Each type of activity results in a type of more of groundwater deterioration.

## GENERAL HYDRO-GEOLOGIC CHARACTERISTICS OF THE MEDITERRANEAN BASIN

### Climate and geomorphology

The Mediterranean countries have many similarities, especially in the climate, geomorphology, and structures of river and groundwater basins. These conditions make them very unique and different, compared with the Atlantic countries. The prevailing weather is a transition between humid and arid weathers. Rainy autumns and winters are generally followed by very dry springs and summers. Moreover, rainfall is not uniform over the season and even over the day. *This decreases the opportunities for rainfed agriculture and increases the dependance on irrigated agriculture.*

The geomorphology, on the other hand, affects the size of river and groundwater basins over the countries. Surface water basins are generally small in size, except the Nile basin; while groundwater basins are of limited are-

al extent, except the alluvial basins of some rivers in the European countries.

The Mediterranean basin can, however, be distinguished into two regions, the northern on one hand, and the southern and south-eastern, on the other hand. The major differences between the two regions are in the rain intensity, being 60 times in the north compared to the south; and in the magnitude of evapotranspiration, being maximum in the middle-southern section. These result in the deterioration of the water (surface and groundwater) and the soil due to the direct evaporation and salt accumulation in the soil.

### Hydrogeologic conditions

The geologic structure of the basin is the main factor affecting the extent of the aquifers. The major portion of the basin is affected by the Alpine chain (the northern countries and Morocco), which is characterized by a complex system of structures. This portion is characterized by a great number of relatively small aquifer systems. The southern portion, extending from south Tunisia to Sinai, is characterized by simple structures and relatively extensive aquifer systems.

The main types of aquifers dominating in the Mediterranean basin are: (i) the carbonate karst systems; (ii) the alluvial systems; and (iii) the multi-layered sedimentary systems (see **figure 1**).

*The karst system*, which is the main system in the basin, is characterized by limited sub-systems, irrespective its large areal extent. The system itself is very complicated from the hydro-geologic point of view due to the layering and the type of hydraulic behavior of the fissures and the complex. The major karstic systems are located in the northern portion of the Mediterranean basin; while the south is characterized by less important aquifers in terms of their areal extent and potential. The karst system also extends off-shore, being thus affected by sea water.

*The alluvial aquifer systems* are recognized mainly in the Po river basin in Italy and the valley in Egypt. They are made of sediments deposited in the main river grabens. The aquifers are characterized by high hydraulic conductivities and low hydraulic pressures. They are essentially recharged directly or indirectly from the rivers they come in contact with and along their boundaries from adjacent major aquifer systems (Nubian sandstone). Groundwater is either under phreatic or (semi)-confined conditions.

*The sedimentary aquifer systems* constitute generally of several horizons, separated by (semi)-confining layers. In the northern portion of the Mediterranean basin (including Morocco), the system limited in areal extent, and is confined to the littoral zones. In the southern portion, the system is of larger areal extent. Recharge of such systems is a function of the climatic conditions and the lateral underflow along their boundaries with pro-

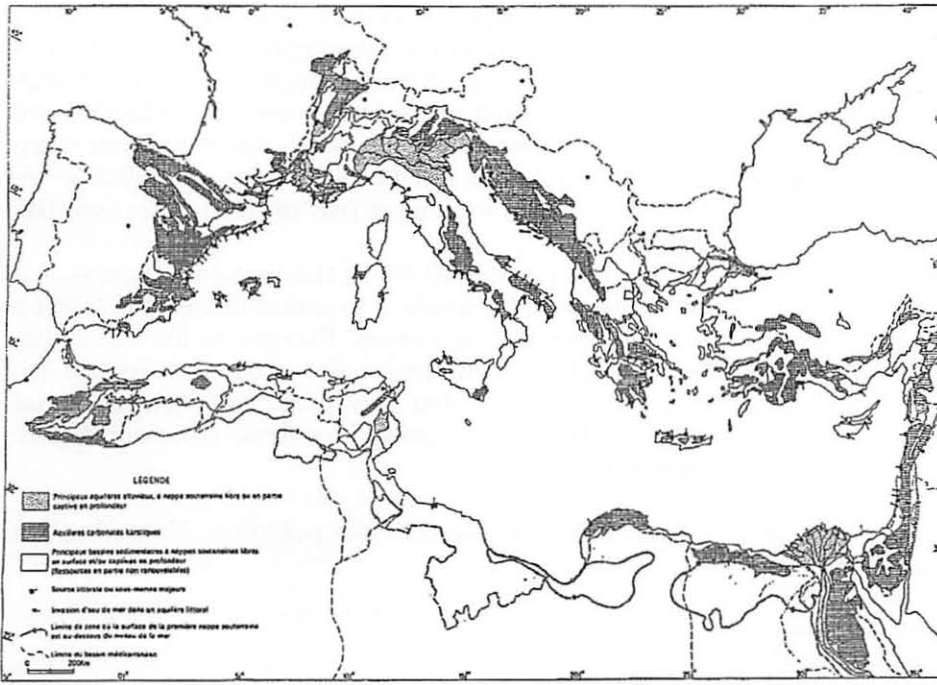


Fig. 1. Main aquifer systems in the Mediterranean basin (Nile).

ductive aquifer systems, and sometimes as a result of irrigation. Examples of such systems are the Moghra in Egypt and the Nubian sandstone in Egypt and Libya.

#### IMPORTANCE OF GROUNDWATER IN THE MEDITERRANEAN BASIN

##### Water use in agriculture

The agricultural sector has historically been and will probably continue to be the major water consuming sector in the basin. Percentages may differ from one country to another, based on the irrigated areas. **Figure 2** illustrates the projected annual water allocations to the irrigation sector (2000 and 2025), based on the irri-

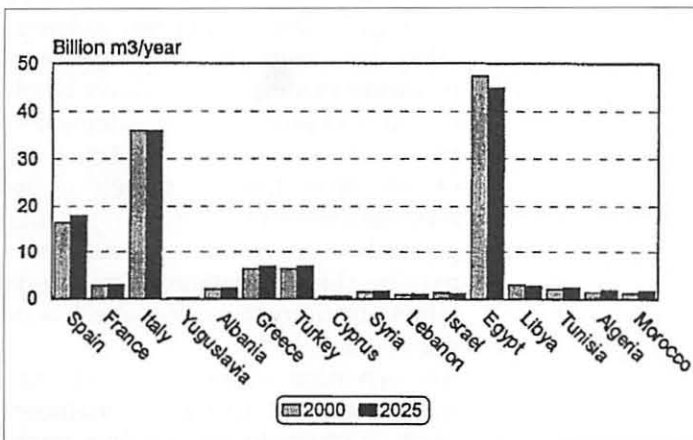


Fig. 2. Projected water allocations to irrigated agriculture in the Mediterranean countries.

gated areas in 1980 (Plan Bleu). It can be observed that a continuous increase in water allocations to the irrigation sector is expected in the southern countries. Compared with the available water resources, these values may indicate a continuous mining of non-renewable water resources.

##### Importance of groundwater

Groundwater plays an important role in the overall water management of many Mediterranean countries. Percentages of groundwater use compared to the overall withdrawn water vary from 5 to as much as 87% (ROSTAS/IHE/ACSAD, 1988), as illustrated in **table 1**. These ratios are expected to increase in the future due to the limitations imposed on surface water (streamflow). Even in those countries where streamflow is ensured and water is abundant, groundwater

is and will continue to play an important role as a safe source for municipal water. Accordingly, groundwater protection should be a national and regional goal in the basin.

#### FARMING CONDITIONS AND THEIR POSSIBLE IMPACTS ON GROUNDWATER

##### Farming conditions and accompanying activities

The farming conditions in the Mediterranean basin include, but may not be restricted to the following:

- 1) Irrigated agriculture is prevailing and will probably continue to be the main water consumer.
- 2) Due to the increasing demand on water by the other sectors, water reuse is experienced, including do-

Table 1 Percentage of groundwater contribution in the overall water use in some Mediterranean countries.

Country	Water Use ( $10^9$ m <sup>3</sup> /y) for the 1990s*			% groundwater use
	streamflow	groundwater	others	
Algeria	13.0	2.0	0.075	13
Egypt	55.5	5.5	2.036	9
Lebanon	3.9	0.2	0.000	5
Libya	0.0	1.7	0.248	87
Morocco	23.2	3.0	0.006	11
Syria	22.1	2.7	0.003	11
Tunisia	2.7	1.5	0.019	36

mestic and industrial sewage and agricultural drainage water.

3) Applied water is generally higher than the evapotranspiration to satisfy the leaching of accumulated salts and productivity of lands.

4) Agro-chemicals and pesticides application became a general trend in farming to ensure food security of growing populations and limited lands.

5) Various activities are accompanying farming, including cattle raise, and food and dairy processing.

6) Groundwater withdrawals are increasing to ensure the satisfaction of water requirements, especially irrigation.

### Impacts of farming conditions

Agricultural land use and cultivation practices have been shown to exert major influences on groundwater quality (table 2). This is due to their wide distribution as being of a diffuse character. of particular concern is the leaching of fertilizers and pesticides from regular intensive cultivation of cereal and horticultural crops. The changes in groundwater quality brought about by the clearing of natural vegetation and ploughing up of virgin land for new cultivation are also important. The impact of cultivation practices on groundwater quality is greatest, as are most anthropogenic effects, where relatively shallow, unconfined aquifers are used for potable supply in areas where there is no other alternatives.

Detailed scientific investigations demonstrated that high leaching to groundwater of nitrate and other mobile ions occurred from many soil types under continuous cultivation sustained by large applications of inorganic fertilizers. Fertilizer use has doubled in the majority of the European countries between 1950 and 1970, and the percentage of nitrogen in all fertilizers increased from 6 to 20 per cent. In the developing countries, fer-

tilizer use has tripled since 1975 (Conway and Pretty, 1991). The impact of the unsaturated zone on nitrate is just a delay in reaching the groundwater. In the groundwater environment, considerable changes in load occur. However, dependance on data obtained from deep boreholes may not reflect the severity of pollution already present in the upper part of the aquifer (see figure 3).

An the other hand, many of the pesticide compounds are unlikely to be leached to groundwater due to their physico-chemical properties. Exceptions include carbamate insecticides and herbicides of the carboxylic acid, triazine and phenylurea groups, inspite of the rapid biodegradation rates quoted for these compounds (see figure 4).

Increasing salinity is one of the oldest and most widespread forms of groundwater pollution. Many, but not

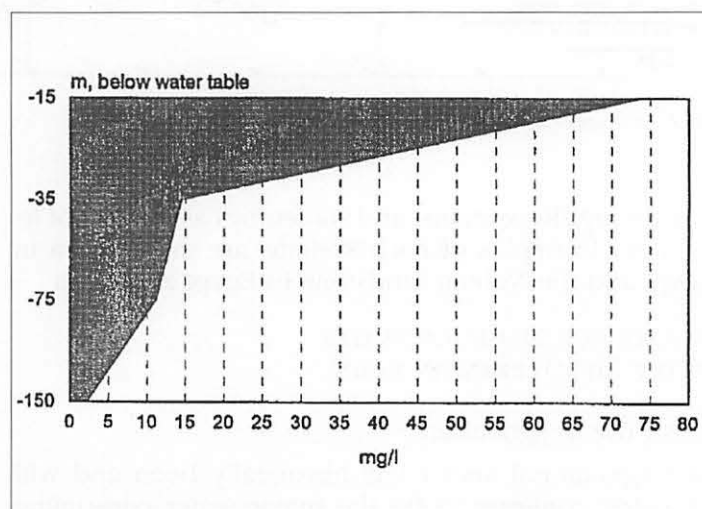


Fig. 3. Vertical change in nitrogen content in groundwater (Nile Delta alluvium).

Table 2 Groundwater pollution from agricultural activities.

Activity	Principal Characteristics of Pollution				
	Distribution	Category	Types	Relative hydraulic surcharge	Soil-zone by-passed
Agro-chemicals	r	D	no		
Irrigation	r	D	sno	*	
Sludge & slurry	r	D	nos		
Wastewater irrigation	r	D	nosp	*	
Livestock rearing	r	P	pno	*	+
Crop processing	r	P-D	nsop	*	+
Saline water intrusion	ur	D-L	s		na

Distribution: u=urban, r=rural.  
 Category: P=point, D=diffuse, L=line.  
 Types of pollutants: p=faecal pathogens, n=nutrients, o=organic micro-pollutants, s=salinity.  
 Relative hydraulic surcharged: \* to \*\*\* scale of impact.  
 na: not applicable.

all, forms of waterlogging and salinisation are related to low irrigation efficiency and lack of proper drainage. Over-irrigation without adequate drainage can cause rises in groundwater levels which result in soil and groundwater salinisation from direct evaporation. Leaching of salts from the soil merely transfers the problem to the underlying groundwater. Additional salt loads may be due to seepage from desert lands during reclamation and leaching of soil.

An important water quality change resulting from the poor management of groundwater is saline intrusion, which occurs when saline wa-



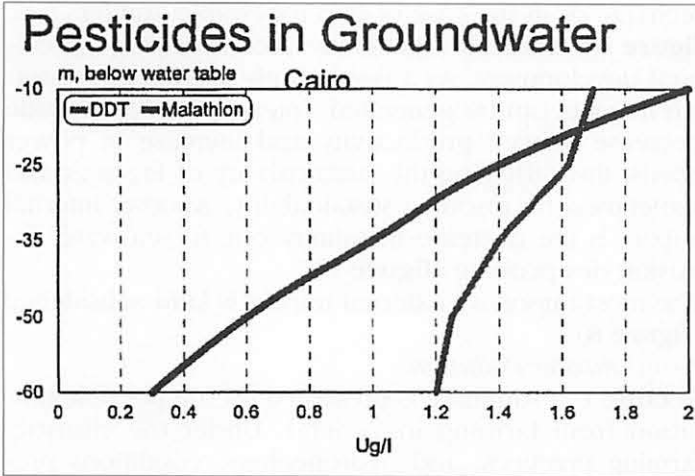


Fig. 4. Pesticide content and behavior in groundwater (near Cairo).

ter displaces or mixes with fresh water in an aquifer. The problem is encountered in three possible circumstances: (i) where there is upward advance (upconing) of saline water of geological origin; (ii) where there is lateral movement from bodies of saline surface water; and (iii) where there is invasion of sea water into coastal or estuarine aquifers. The position of the saline water-freshwater interface in a coastal aquifer is governed by the hydrostatic equilibrium between two fluids of different densities. Increasing groundwater withdrawals lowers water levels and reduces flow towards the sea. Lowering of groundwater levels changes the hydrostatic conditions and causes local upconing of saline water below abstraction wells. On the other hand, where groundwater withdrawal from a group of wells is sufficient to cause regional lowering of water levels or reversal of hydraulic gradients, then lateral movement of the interface will occur. The resulting pollution of the groundwater is difficult to reverse.

**VULNERABILITY OF GROUNDWATER TO POLLUTION UNDER THE FARMING CONDITIONS OF THE MEDITERRANEAN COUNTRIES**

The vulnerability of groundwater to externalities, including farming activities, depends on the first place

on the internal characteristics which determine the extent to which the aquifer system can play in modifying pollution.

**Internal vulnerability of groundwater to pollution**

If we consider the intrinsic properties of the aquifer systems prevailing in the Mediterranean basin, a simple relative qualitative classification can be made (see also the British-Wales model), as shown in **table 3**.

It can be concluded that the majority of the aquifer systems in the Mediterranean basin fall under the moderate vulnerability to pollution class, irrespective the confinement of some of these systems and the large depths to groundwater.

The main reason behind that is the impact of surface activities on the removal or thinning of the upper confin-

**Table 3 Classification of groundwater vulnerability classes in the Mediterranean basin.**

Aquifer system	Type Groundwater head	Relative vulnerability class
Karst (Carbonate)	Unconfined/artesian	Low
	Unconfined/low	High
	Confined/both	Low
Alluvial	Unconfined/deep groundwater	moderate to low
	Unconfined/shallow groundwater	high
	Confined/upward leakage	low
Sedimentary	Confined/downward leakage	moderate to high
	Unconfined/artesian	low
	Unconfined/low pressure	moderate to low
	Confined	low

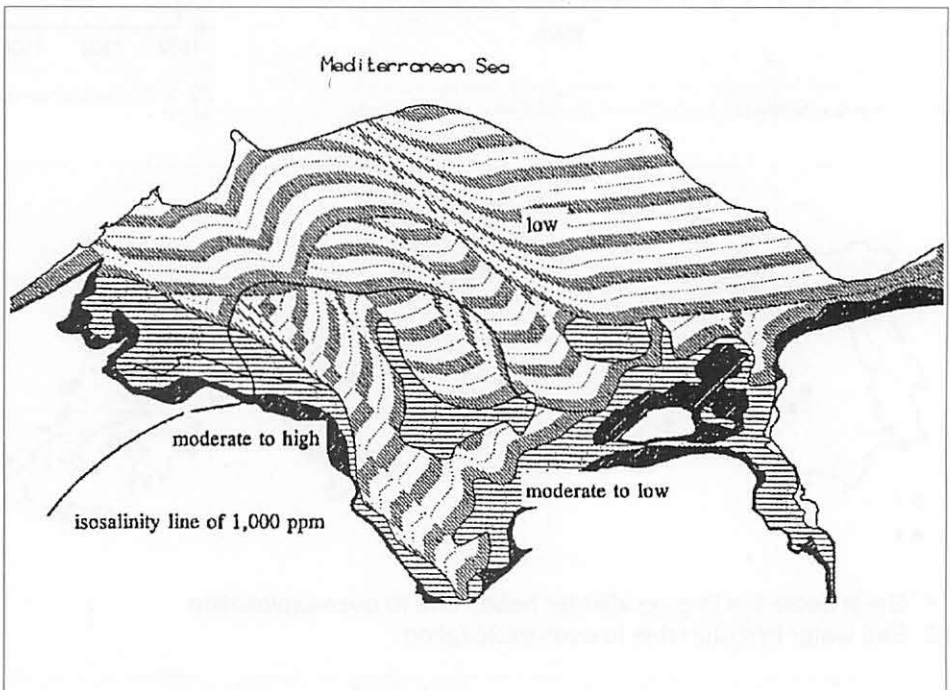


Fig. 5. Groundwater vulnerability to pollution in the alluvial aquifer (Nile Delta of Egypt).

ing/protecting layer(s). Many countries in the basin have already produced groundwater vulnerability maps either for the whole territory of the country or for the most populated parts (see **figure 5**).

#### Impacts of farming conditions

The determination of the impact of any activity on groundwater needs, in the first place, a proper monitoring system that furnishes historic data.

In that respect, the countries of the north are more developed. The elements to be monitored include, in addition to the physical factors (groundwater levels, saline intrusion), the quality factors. In the following paragraphs, examples of effects are given from various Mediterranean countries.

**Extensive Exploitation.** Extensive exploitation of groundwater is a general trend in the arid regions of the basins, where groundwater withdrawals exceeds

recharge or in the case of non-renewable aquifers (see **figure 6**). These are generally accompanying agricultural development. As a result, both internal and external impacts can be generated. Internal impacts include decrease in well productivity and increase in power needs, thus affecting the sustainability of facilities and sometimes the resource sustainability. Another internal impact is the decrease in salinity due to sea water intrusion or upconing (**figure 7**).

The most important external impact is land subsidence (**figure 8**).

#### Groundwater Pollution.

In **table 1**, a summary is presented for the possible pollution from farming in general. Under the climatic, farming practices, and hydrogeologic conditions prevailing in the Mediterranean basin, one can expect to find all types of farming pollutants, with different degrees.

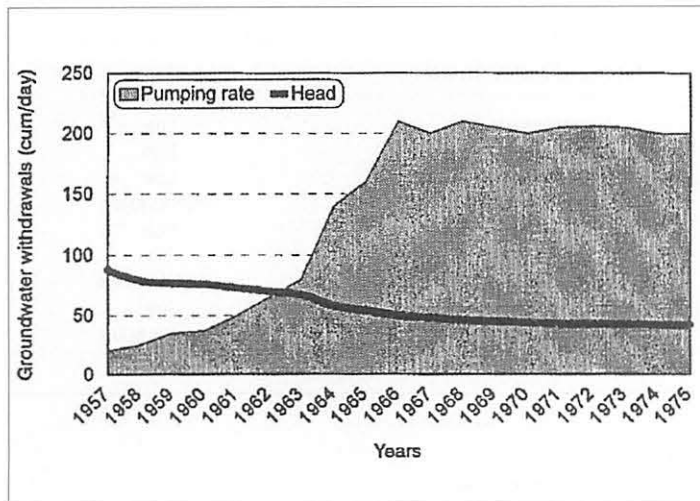


Fig. 6. Drop in groundwater heads due to over-exploitation (Kbarga, Egypt).

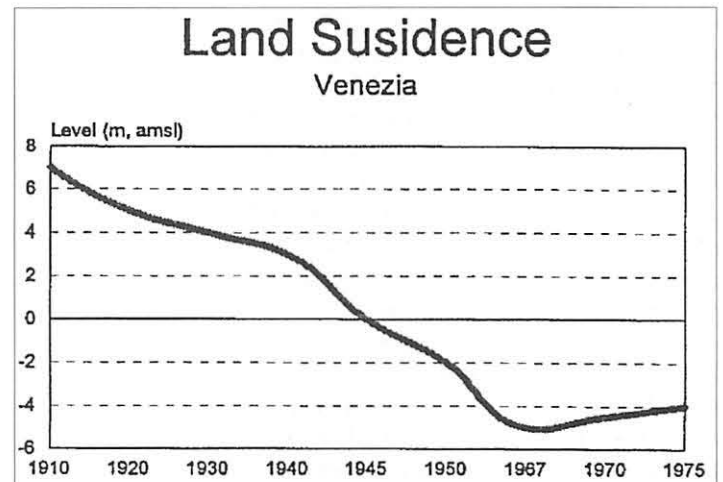


Fig. 8. Land subsidence accompanying groundwater extensive withdrawals (Venezia, Italy).

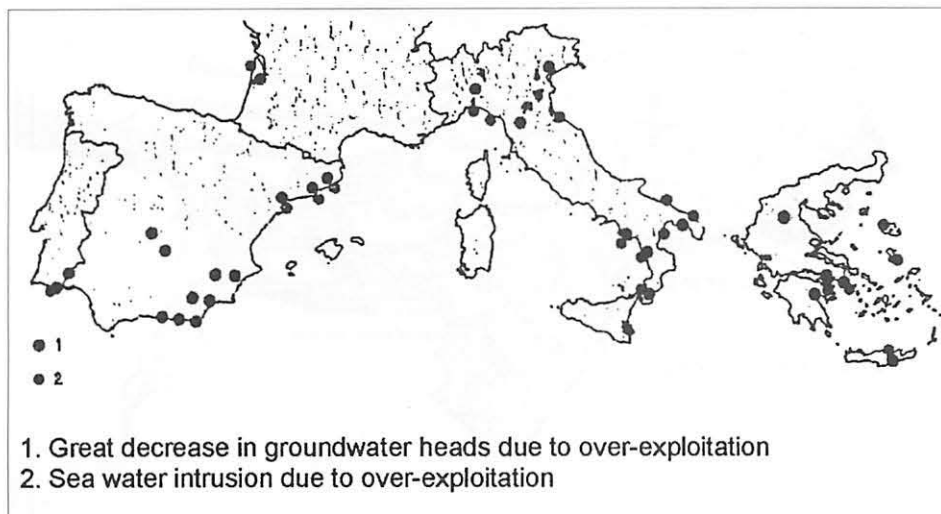


Fig. 7. Situation in some European countries due to over-exploitation (Fried et al.). Source: Groundwater resources of the EC (Fried et al. RIZA).

1) Waterlogging due to over-irrigation in river basins (see **figure 7**) is accompanied and salinisation.

2) A diversity of pollution resulting from agro-chemicals is observed, with different degrees of severity, in many Mediterranean countries (**figures 3 and 4**); thus restricting groundwater use for domestic purposes especially in the rural areas.

3) Irrigation with wastewater, on the other hand, may result in severe groundwater pollution, especially in arid regions and with a poor or no treatment.

4) Food and dairy processing, especially when sewage is not properly disposed, would result in pollution

## CATEGORIES USED FOR GROUNDWATER VULNERABILITY CLASSIFICATION IN ENGLAND AND WALES

*Soils of high leaching potential*

Soils with little ability to attenuate diffuse source pollutants, and, in which non-adsorbed diffuse-source pollutants and liquid discharges will percolate rapidly. Three classes are recognized:

H1 Soils which readily transmit liquid discharges because they are either shallow, or susceptible to rapid by-pass flow directly to rock, gravel, or groundwater.

H2 Deep, permeable, coarse-textured soils which readily transmit a wide range of pollutants because of their rapid drainage and low attenuation potential.

H3 Coarse-textured or moderately shallow soils which readily transmit a wide range of pollutants and liquid discharges, but which have some ability to attenuate adsorbed pollutants because of their large clay or organic matter contents.

*Soils of intermediate leaching potential*

Soils which have a moderate ability to attenuate dif-

fuse source pollutants, or in which is possible that some non-adsorbed diffuse-source pollutants and liquid discharges could penetrate the soil layer. Two classes are recognized:

I1 Soils which can possibly transmit a wide range of pollutants.

I2 Soils which can possibly transmit non-or weakly adsorbed pollutants and liquid discharges, but which are unlikely to transmit adsorbed pollutants.

*Soils of low leaching potential*

Soils in which pollutants are unlikely to penetrate the soil layer because water movement is largely horizontal, or they have a large ability to attenuate diffuse pollutants. Generally they are soils with a high clay content. It must be recognized that run-off from these soils may contribute to groundwater recharge elsewhere in the catchment.

problems on the local scale.

## STRATEGIES FOR THE CONTROL OF GROUNDWATER POLLUTION

## Findings

- 1) Groundwater represents an important source of fresh water in the Mediterranean countries, especially in the southern region; and will become more important in the future due to the limitations imposed on available surface water and the increasing demand on water.
- 2) The groundwater vulnerability to pollution in the basin is generally moderate to high, thus reducing the capacity of the system to attenuate pollution.
- 3) The present status of farming practices is dictated by physical and human factors that are responsible for the poor farm water management.
- 4) The major groundwater pollutants include land subsidence, salinity, nitrogen, and pesticides.

## Recommendations

Protection measures are generally more feasible than corrective measures. Protection of such a precious resource from degradation requires proper measures, including:

- 1) The implementation of monitoring system(s).
- 2) Development of proper tools for groundwater protection, e.g. hydrogeological maps, groundwater potential maps, groundwater vulnerability maps, etc.
- 3) Enforcement of laws including licensing and types of agro-chemicals.
- 4) Caution with the use of sewage water in irrigation, which should be limited to regions of low vulnerability.

- 5) Development of performance indicators for timely action and decision making.
- 6) Increasing public awareness of the need for conservation of the resource. ●

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