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UNCONVENTIONAL WATER RESOURCE USE AND MANAGEMENT

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ABSTRACT

In arid and semi-arid regions, as most of the Mediterranean countries, the use of unconventional water resources has been seen to play an ever more important role in satisfying the increasing water requirements. It is quite difficult to make a classification of the unconventional water resources. Water quality is the most important factor in managing unconventional water resources; quality is a complex factor since there are many water quality parameters which vary with continuity. Two major categories of unconventional water resources could be identified, the first including waters with high organic matter and microorganism content (such as municipal wastewater) and the second including waters with high saline concentration (such as sea and brackish water, some industrial and agricultural wastewaters, etc.). In many Mediterranean countries municipal wastewater reuse has been practised for a long time and actually represents the most relevant use of unconventional resources. In this paper a network is presented which highlights the main indirect effects of the agricultural use of municipal wastewater. The results of research and the analysis of case-studies lead us to the conclusion that the development of irrigation with wastewaters may have a certain importance in the Mediterranean countries. There are good reasons for updating specific and realistic regulations, which would be based on the recent WHO guidelines.

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RESUME

Dans les régions arides et demi-arides comme la plupart des pays de la Méditerranée, l'utilisation de ressources hydriques non conventionnelles résulte très important pour la satisfaction des croissante besoins hydriques. Il est très difficile faire une classification des ressources hydriques non conventionnelles. La qualité de l'eau est le plus important facteur dans la gestion des ressources hydriques non conventionnelle; la qualité est un facteur complexe parce que les paramétres de qualité de l'eau sont nombreux et ils varient avec continuité. On pourrait saisir deux grandes catégories de ressources hydriques non conventionnelles, la première incluant d'eaux avec d'élevées substances organiques et contenu de microorganisme (comme les eaux usées municipales) et la seconde incluant d'eaux avec une élevée concentration saline (comme l'eau de mer et saumatre, les eaux usées industrielles et agricoles, etc.). Dans beaucoup de pays méditerranéens le réutilisation des eaux usées municipales a été pratiqué pendant beaucoup de temps et maintenant il représente le système d'utilisation plus important des ressources hydriques non conventionnelles. Dans cette travail on presente un graphe qui met en évidence les principaux effets indirects dans l'utilisation en agriculture des eaux usée municipales. Les résultats de la recherche et l'analyse des cas étudiés nous permettent de conclure que le développement de l'irrigation par eaux uséess est d'importance pas négligeable dans les pays méditerranéens. Il y a des valides raisons pour la promulgation d'une normative spécifique et réaliste, en se fondant sur les directives WHO récentes.

1. PRELIMINARY CONSIDERATIONS

Each water resource and each use has specific spatial and temporal distributions of characteristics of water quantity and water quality variables (Yevjevich, 1978).

Man has usually modified the characteristics of natural resources in order to satisfy water demand; water quality has been modified by means of treatment plants, temporal water distribution by means of storage regulation, resource location by means of supply, conveyance and distribution works. Recently attempts have also been made to modify water quantity increasing rainfall by seeding clouds with silver iodide. Water resource management should integrate all these activities in a rational and economical way.

The main uses of water are: civil, industrial, agricultural, hydroelectric, aquatic life, recreation and navigation. Some of these uses are well-known and acknowledged while others, such as recreation or acquatic life conservation, have sometimes been classified under other headings. The removal of salts and waste elements (both with a natural or artificial origin) and the sediment transport in water courses for beach protection could also be considered as water uses.

Conventional water resources generally include surface and ground water. At the moment there is no general consensus on how "unconventional water resources" are to be defined. Generally speaking, resources other than "good quality surface or ground water" are termed "unconventional resources". Examples of such resources are wastewater, brackish water and sea water; other water resources include water which has precipitated from the atmosphere (rain, snow, ice, water vapour and condensation) and is used directly, and the increase in water resources due to the artificial increase in rainfall. These definitions of unconventional water resources include quite different types of water as regards spatial and temporal distributions of quantity and quality.

The main unconventional water resources are waste, brackish and sea waters. These differ from the "surface" and "ground" water resources, as far as quality is concerned. The fact that there are many water quality parameters which vary with continuity should be kept in mind. Moreover, some quality parameters assume different meanings according to the type of resource they are found in; for example, this is the case of the ratio between microbiological indicators and pathogenic microorganisms which is different in surface water versus wastewater. The definition of wastewater is imprecise too. In fact most water courses (especially rivers) and groundwaters receive wastewater discharges which influence quantitative and qualitative characteristics of water in downstream sections. Furthermore, the qualitative characteristics of wastewater are not uniform (depending on use and treatment) and are not specific (they can also be found in surface and groundwater).

2. WATER QUALITY AND UNCONVENTIONAL RESOURCES

2.1 The role of water quality

As previously stated water quality is the main factor in managing unconventional water resources. Here some considerations on water quality regarding unconventional water are reported.

Water quality is the most complex of the various factors (quantity, space, time) affecting water suitability for each use. There are many parameters which characterize water quality. Chemical quality of water depends on the type and entity of dispersed solids (dissolved or suspended); the physical characteristics and the presence of microorganisms can also affect the suitability of the water for each use.

Man can intentionally modify water quality by means of treatment plants; he can also unintentionally affect water quality (generally in an undesirable way) during use. All water quality parameters can be modified by means of suitable treatment each with quite different costs. In managing unconventional resources, treatment costs play a very important role; these costs can range from about 1/100 US dollar per m^3 (e.g. simple sand removal) to 1/10 US dollar per m^3 (e.g. partial removal of organic matter). With more advanced treatments (strong reduction of organic matter, suspended solids, microorganisms, nutrients, etc.) the cost increases; the cost for the desalination of sea water (strictly related to energy cost and plant type and size) are always over 1 US dollar per m^3.

As we can see, in some cases the required modification of water quality can be very expensive (also with respect to supply, conveyance and regulation costs); for this reason the guideline, given in 1958 by the Social Council of the O.N.U., according to which no water of superior quality, unless it is extremely abundant, should be used for a purpose for which a lower quality of water can be tolerated, is widely accepted.

Often, treatment of water before use has been considered apart from treatment after use (before discharge into water bodies). The difference between these kinds of treatment is of no importance if we accept that the only aim of treatment is to protect downstream uses (including in situ uses such as recreation and aquatic life).

Quality of discharges can be controlled not only by treatment but also by modifying water utilization processes. As a matter of fact in many industries and in irrigation, water "consumption" (modifications in quantity), water use and water "pollution" (modification in quality) are conditioned by utilization modalities. A further variable is given by the recycling of water within an industrial factory.

For example in sprinkler irrigation drained or deep percolated waters have a higher saline concentration in comparison with surface irrigation, as a consequence of reduced water volumes due to the higher hydraulic efficiency (water consumption is almost the same). Microirrigation seems to permit a slight increase in saline concentrations and hydraulic efficiency and a decrease in water consumption and total salt contribution.

2.2 *Potential uses of unconventional water resources*

As we have seen it is difficult to classify unconventional waters. However, we can select two main categories. In the first we can include waters which have a high content of dissolved solids. Sea water, wastewater from some industrial processes, drainage water from agricultural land, some surface and ground waters with a high level of salinity which occurs both naturally or because of discharge, may all be included in this category. The treatments for the removal of dissolved solids are usually extremely expensive; the salts are undesirable elements for almost all kinds of uses (excluding navigation, marine aquatic life and some forms of recreational use). Less remunerative utilizations such as irrigation can use brackish water only without expensive treatments; this occurs when the characteristics of soil and crops, the non-excessive saline concentration and the irrigation and drainage modalities limit the disadvantages linked to salinity (i.e. reduction in productivity) to acceptable levels. Unconventional water resources, particularly brackish water resources, play an important role in periods of drought, when they can supplement conventional waters for irrigation (Barbagallo et al., 1992; Hamdy, 1992).

The partial elimination of dissolved solids from brackish water for civil and industrial purposes may be opportune (by means of reverse osmosis or synthetic resins). The desalination of sea water is beneficial from an economic point of view only when water is an extremely valuable comodity (for example, in small islands or in very arid areas) or when there are plants which can keep the costs low by carrying out the double function of producing desalinated water and power (Micale, 1989).

The second category of unconventional resources should comprise all those waters which contain residues of animal and/or vegetable origin and whose quality is consequently characterized by a high content of organic substance, nutrients (azote, phosphorous, potassium) and microorganisms. Municipal wastewater, zootechnic wastewater and food industries effluents, not to mention some water courses which receive wastewater discharges, may all be included in this category. The substances in these water, with few exceptions (i.e. pathogenic microorganisms), do not pollute cultivated soils; consequently, in many countries of the Mediterranean the use of these waters for irrigation is ideal.

As our time and space is limited we will now pass directly on to the reuse of municipal wastewater which represents a very important resource, offers many agricultural and environmental advantages, and has characteristics which are uniform enough to permit us to make some generalisations.

2.3 Reuse of wastewater for irrigation and subsequent environmental effects

As previously observed, the reuse of wastewater in Mediterranean conditions is the most important and practical of all the possible forms of unconventional resource use. Generally speaking this reuse is most common in the inland areas which are located at a suitable height above sea level and which are near areas to be irrigated. In some cases it is also opportune to reuse the effluent of the rainy season by constructing suitable reservoirs (Shuval et al., 1986; Barbagallo et al., 1990).

There are many factors which interact in a complex way creating a series of processes which make the evaluation of the environmental effects of wastewater reuse extremely difficult (Indelicato et al., 1992).

The main actions related to the use of municipal wastewater concern the absence of a discharge in water bodies, the contribution to the soil of macroelements (nutrients, salts, etc.) microelements (boron, heavy metals, etc.) and water, and the contribution (to crops, soil, groundwater, etc.) of micro- organisms. Each of these actions produces effects of different order (primary, secondary, etc.), as shown in the cause- condition-effect network of fig. 1. The presence and the entity of the effects depend on a single condition or on a combination of conditions.

Some less important or less common effects (indicated in the network by a dotted line) are represented by the contribution to the soil of organic matter and by the diffusion in the atmosphere of volatile and/or gaseous substances.

Figure 1 shows the prevalence of indirect effects caused by irrigation with wastewater. For each link in the network it is necessary to develop a relationship which quantifies the effects on the basis of the values assumed by the parameters characterizing impact actions and conditions. In some cases this is quite straightforward as the results of basic investigations are available. This is the case of the effects of saline content of water on soil and crops; evaluation criteria have already been developed in order to determine the suitability of water. However, most of the cause-condition-effect relationships require further research in order to acquire a basic knowledge and/or to interpret and use the results obtained in the past. In some cases it is necessary to modify evaluation criteria already established.

Basic investigations, field surveys and experimental tests on the effects of municipal wastewater irrigation have been carried out in Sicily and have mainly concerned (Indelicato at al., 1988):

- the contribution of nutrient macroelements and the effects of their accumulation in the soil (particularly phosphorous and potassium) or their deep percolation (nitrogen);
- the contribution of boron to the soil and the related effects on crops;
- the contribution of micro-organisms and the related effects on groundwater and agricultural products (the effects depending also on irrigation methods);
- the water contribution to the soil with particular reference to the actual and potential volume of utilizable wastewater.

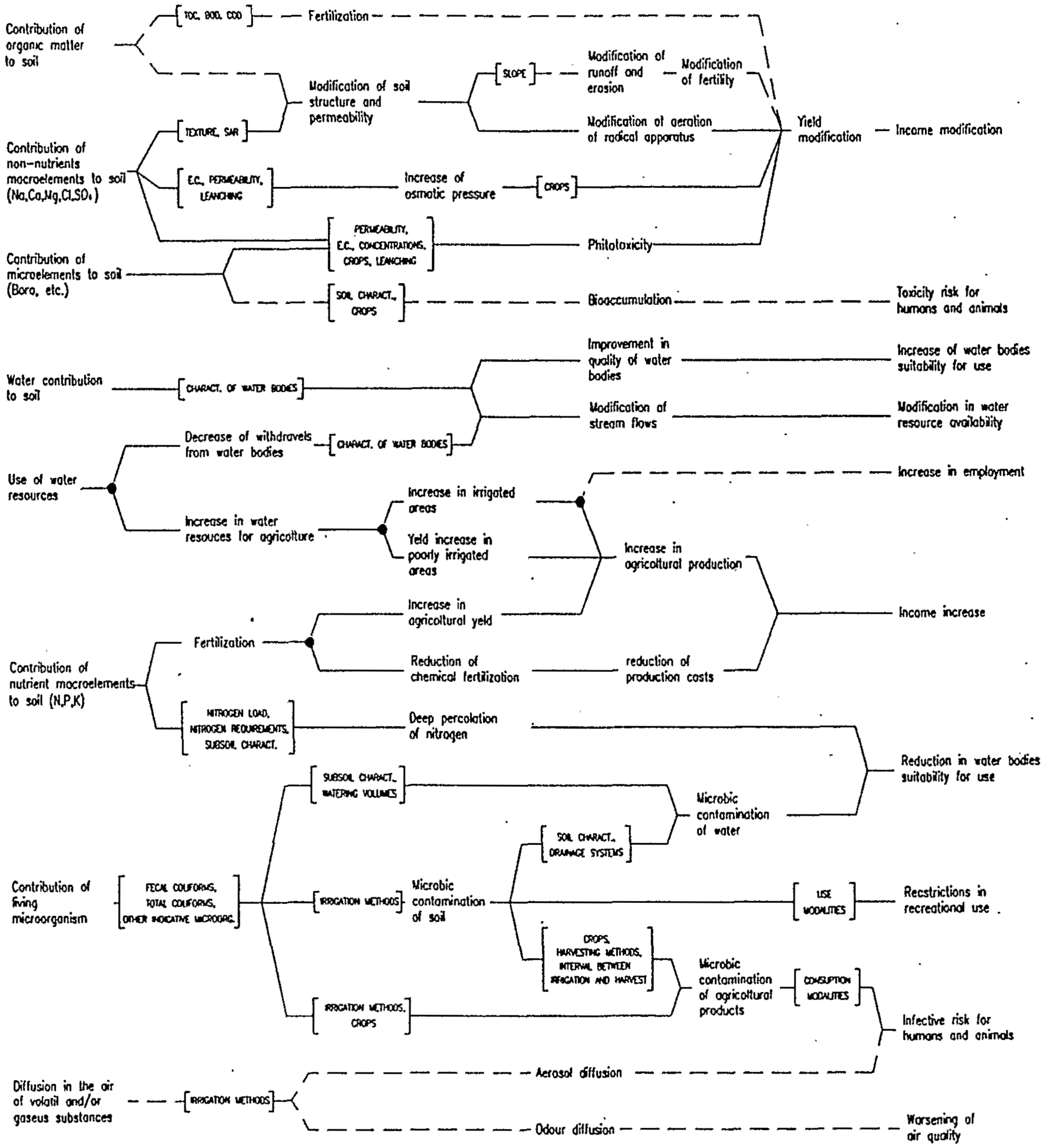

FIG. 1 - Environmental effects of wastewater reuse for irrigation

2.4 Localized wastewater irrigation in order to reduce sanitary risks

The main problem of wastewater reuse is constituted by sanitary risks. This problem can be solved both by suitable treatment or by acting on irrigation methods and modalities.

Health risks connected to wastewater agricultural use can be sufficiently reduced by employing localized irrigation methods. In fact in small reuse systems the realization of advanced depuration plants makes reuse rather expensive and unreliable because of operational difficulties. Thus, in these cases it is best to limit wastewater treatment (for example just to sedimentation or oxidation pond) and to irrigate with methods which avoid any contact of crops with wastewaters (Tamburino et al., 1989).

Localized irrigation methods, such as capillary sub-irrigation and drip irrigation, could reduce health risks, especially if they are employed in arboreous cultivations, but often occlusion of emitters is a problem.

Experimental investigations have been carried out in order to study the causes of occlusion of emitters. Different emitters have been tested with wastewaters treated at different levels. The best results have been obtained with microtubes with a diameter between 2 and 4 mm (Capra et al., 1985; Barbagallo et al., 1988). The delivered flows are generally superior to those of standard drippers; this produces some disadvantages such as the increase in pipe diameter and cost. Such disadvantages are partly reduced in irrigation of arboreous cultivations which have fewer emitters per unit area. It is usually possible to reduce delivered flows to acceptable values by using low pressures and microtubes of sufficient length. Good results have also been obtained with elastic fissured emitters (Tournon, 1972, 1979).

In order to minimize the risk of occlusion, filtration by metal cartridges with holes between 0.5 and 1.5 mm inferior to half of the orifices of employed emitters, is sufficient. Cleaning out operations are simplified with these filters (in comparison with filters of nylon fabric with smaller openings). Moreover, the cleaning out operation of these filters does not have to be repeated so often even if primary effluent has been employed.

Bacteriological investigations carried out on localized irrigation systems have shown a low or absent microbic contamination of crops (grapes). Even in those cases where contact of grapes with untreated wastewaters has been simulated, a rapid inactivation of infectious micro-organisms has been observed due to environmental factors (in particular solar radiation) hostile to micro-organism survival (Barbagallo et al., 1988).

3. SOME REMARKS ON WASTEWATER REUSE IN THE MEDITERRANEAN COUNTRIES

No complete or reliable sure information on wastewater reuse in the Mediterranean countries is available. Here some remarks, which cannot be termed exhaustive, on wastewater reuse are reported from various literature sources.

There are over 200*10^6 inhabitants in the Mediterranean countries of which 70% is concentrated on the coastal areas, which are approximately 46*10^3 Km long.

The water availability varies considerably from one country to another according to climatic conditions. The Northern countries (France, Italy) and some Eastern countries of the Mediterranean basin (Albania, Greece, Lebanon, Turkey, Yugoslavia) have greater availability of water resources, which however are not fully made use of. The more Western countries of the basin (Algeria, Morocco, Portugal, Spain) and the island of Cyprus have less water resources. In some of these countries (Algeria, Greece, Italy, Turkey) water resource availability varies from region to region; e. g. Sicily and Sardinia are a case apart from the rest of Italy as they have a more arid climate. In the South and the East of the basin there are countries with very few water resources (Egypt, Israel, Libya, Malta, Syria, Tunisia); in these countries unconventional water resources are widely used: wastewater in Egypt and Israel; fossil groundwater in Tunisia and Libya; desalinated water in Malta.

At the moment the irrigated area in the Mediterranean countries amounts to more than 16*10^6 ha. In some regions, especially in the South and the East, irrigation uses up the greater part of the water resources.

There is a remarkable difference in the Mediterranean countries when dealing with regulations governing wastewater reuse.

In countries such as Israel, Italy, Spain and Tunisia some general regulations exist; in Italy and Spain the regulations can be adapted by the regional authorities. In some countries some technical recommendations have been set down; in other countries it would seem that there are no specific regulations governing wastewater reuse.

The regulations concerning the reuse of wastewater of some countries (i.e. Israel and Italy) are generally based on the WHO (World Health Organization) guidelines published in 1973 and on Californian guidelines. In 1989 the WHO published some more realistic guidelines on crop types, cultivation practices, treatments and required water quality. These guidelines have been adopted by France, while Spain is in the process of applying them.

In Italy the accepted national level is of 2 or 20 total coliforms/100 ml respectively for crop to be consumed raw or cooked, but in fact in some regions, such as Emilia Romagna and Sicily, less rigorous limits are accepted.

Tunisia has rather comprehensive regulations for the reuse of wastewaters. These regulations highlight the need to plan water resource management, regulate the quality of the discharges and lay down the conditions of use of wastewater in agriculture. In particular the control of water quality is laid down; this control does not take restrictions of a bacteriological nature into consideration (Bahri, 1987; Saied et al., 1990).

In Egypt, where there are many important projects for the reuse of wastewaters, some general technical guidelines have been given concerning kinds of treatment and the quality of the effluents (Abdel-Ghaffar et al., 1985; Soulie et al., 1991).

Maltese regulations concerning the protection of water resources, set down in 1988, take into consideration the possibility of using unconventional resources and, amongst others, wastewater, above all because of the lack of resources for potable purposes (Gauci, 1978).

In Greece the existing regulations mainly concern the protection of the environment and the quality of the discharges (Soulie et al., 1991).

In other Mediterranean countries regulations concerning wastewater reuse contain very general guidelines (Soulie et al., 1991). For example, in Syria some guidelines are given concerning physical and chemical characteristics of water for irrigation, while in Algeria some general regulations define unconventional water resources and require that reuse has to be carried out only after authorization.

The reuse of wastewaters is well-known and widely practised throughout the countries of the Mediterranean basin. This practice has been adopted above all in the agricultural sector in order to overcome the problem of water resources common in arid or semi-arid climates. There have also been many experiments aiming at environmental protection.

The experiments carried out in various countries primarily concerned the treatment techniques of wastewater, irrigation methods, type of irrigated crops, etc.

In wastewater treatment simple techniques such as stabilization ponds seem to permit good technical and economical results, especially when there are small reuse systems (Tamburino et al., 1989). Large areas required by oxidation ponds do not represent a limiting factor near small inland towns generally characterized by a low economic value of land.

The development of irrigation with wastewater is quite different from one country to another in the Mediterranean basin depending on their geographical location. While reuse has been developed mainly for agricultural production in the South and in the East, in the Northern countries it has been employed above all for recreational purposes (irrigation of green areas, forests, golf courses, etc.) or, in general, as a means to protect the environment.

In Algeria, the reuse of wastewaters seems to be limited to cases concerning small areas (Soulie et al., 1991).

In France the reuse of wastewaters has been practised for more than a century and has covered almost all the territory, generally in areas of a few hectars (Soulie et al., 1991).

In Greece, with its hundreds of islands and coastlines about 15*10^3 Km long, irrigation with wastewaters seems to have been practised only on a modest scale despite the need for protecting coastal areas from municipal and industrial discharges (Soulie et al., 1991).

Israel considers wastewater as part of the national water patrimony because the growing demand for water cannot be met by the limited availability of conventional water resources. Almost all the produced effluents are treated. About 18 hm^3/year of treated wastewater, which is equal to about 25% of the total water resources, are reused for agriculture. In some areas 80% of water for irrigation comes from wastewater reuse. In Israel sprinkling irrigation is widely used after the effluents have undergone at least a secondary treatment. There are also many cases of surface and drip irrigation (Tamburino et al., 1982).

In Italy studies and research on wastewater reuse for irrigation have been developed over the years, e.g. those carried out on the municipal sewage of Foggia (1932) and Naples (1971). Studies for the planning of the reuse of wastewater have been carried out in Sicily, Calabria, Emilia-Romagna and other regions. The authorities are not aware of most of the cases of wastewater irrigation and generally the rigid constraints imposed by the regulations are not respected. Consequently, the future of wastewater reuse for irrigation in Italy, despite offering many advantages, must overcome considerable hygienic problems and the psycological opposition that is the cause for which public ufficials require high treatment levels. The regional governments could come to play an important role in the future of wastewater irrigation in Italy (Indelicato et al., 1982; Tamburino et al., 1989).

In Morocco the reuse of wastewater has been practised in agriculture for a long time, above all in proximity of the big towns. The untreated wastewater is generally discharged in the water courses and is then used mainly to irrigate orchards, fodder and cereals. Owing to the risk of pollution resulting from such practices, many experiments are being carried out in order to define treatment techniques which are suitable for the Moroccan environment (Soulie et al., 1991).

In Syria in some cases, where untreated wastewater reuse has been adopted, epidemics and a high saline content in the soil has been reported (Al-Rifai, 1985).

Spain, despite being one of the countries where the practice of reuse has been going on for a very long time (there are cases reported as far back as 16th century), does not have a specific plan for the reuse of wastewater (Soulie et al., 1991).

In Tunisia an area irrigated with secondary effluent of about 1.5*10^3 hectars in 1988 is reported. Wastewater, 90% of it from domestic origin, has been normally used to irrigate fodder and cereals, and in some cases golf courses and recreational areas (Saied et al., 1990).

Turkey, although its irrigated areas are amongst the most extensive in the Mediterranean basin, does not seem to have examined in a systematic manner the possibility of wastewater reuse, even if pollution problems in the big industrial areas, above all in the coastal areas, could be partially solved with the treatment and the subsequent reuse of wastewater (Soulie et al., 1991).

4. FINAL REMARKS

In arid and semi-arid regions, as most of the Mediterranean countries, the use of unconventional water resources has been seen to play an ever more important role in satisfying the increasing water requirements.

The use of wastewater for irrigation may have important roles to play, as for instance the valorization of nutrients and the liberation of conventional water resources for other uses with more elevated quality requirements.

Environmental effects of wastewater irrigation, the convenience of wastewater reuse and its operation modalities (kind of pretreatment, irrigation methods, etc.) depend on many factors such as: characteristics of wastewater and soil, nature of subsoil and groundwater, cultivated crops, and availabilty and cost of alternative water resources. Therefore, the best technical and economic solution has to be chosen for each individual case. The results of research and the analysis of case-studies lead us to the conclusion that the development of irrigation with wastewaters may have a certain importance in the Mediterranean countries. There are good reasons for updating specific and realistic regulations, which should be based on the recent WHO guidelines and should encourage the diffusion of planned and regulated reuse.

The role of other unconventional resources, such as brackish water, is not to be forgotten. In general, in the management of water resources more attention should be paid to the quality of water and particularly to parameters, such as saline content, which involve high removal costs or significant negative effects on utilization.

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