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NON-CONVENTIONAL WATER RESOURCES USE IN MEDITERRANEAN AGRICULTURE

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ABSTRACT – Reclaimed wastewater and desalinized brackish or seawater are the two main non-conventional resources developed by the end of the last century in the Mediterranean. Both are intended to solve structural or point problems of water scarcity. Nevertheless, the reclamation and desalination technologies are to be fully developed, although promising possibilities are nowadays in use. Rules and regulations are the main concern for reclamation, since health risks are associated to such practice, while costs are the main limitation for desalination. In any case, decision support systems and other theoretical tools, like Life Cycle Analysis or LCA, will help the stakeholders to decide and fully understand the problems and benefits related to non-conventional water resources.

Key words: agriculture, Mediterranean, water resources, reclaimed water, desalinated water.

INTRODUCTION

Due to the increasing demands of water for agricultural uses and because of the strong competence by the industry and urban uses for the resources in the areas traditionally used for agriculture, there is in a lot of places in the Mediterranean countries structural water scarcity, while in specific points only seasonal or point deficits can be encountered.

There are several possible solutions to overcome this problem; the main ones are: reduce demands to cope with the offer, optimisation of uses, or put other water resources in the market; the last option is being increasingly considered. While in the Mediterranean basin classical or conventional water resources are quite fully exploited or need huge infrastructures for transportation, there are non-conventional resources still available in important quantities.

Non-conventional water resources currently employed nowadays are reclaimed water, brackish (or sea) water and runoff.

Reclaimed water is obtained giving additional treatment to the secondary treated wastewater, using specific reclamation procedures. Brackish water can be obtained from surface or groundwater with high salt contents or from seawater, and runoff is collected after rain episodes.

The first two options (waste and brackish/sea water) are considered increasingly, all around the Mediterranean, because of their continuous availability and nearly constant quality. Alternatively, reclaimed wastewater can be used for agricultural purposes on the grounds of reducing wastewater disposal negative impacts.

When trying to implement non-conventional water use for agricultural purposes, several considerations must be dealt with. First of all is the economic one, followed by the social implications; and for reclaimed water the health-related aspects. Finally, technical aspects are always important.

Economic studies are needed from the planning phase on, and must compare the prices of reclamation or desalination with the cost of having conventional water resources. As the technologies to be employed are evolving, economic studies are not definitive and can be revised from time to time. The present discussion is focused in the desalination costs associated with the use of high-energy consuming membrane techniques (e.g. Reverse Osmosis).

The reclamation procedures must guarantee that the original resource (wastewater) is treated in a way that guarantees an acceptable risk related to reuse and a quality enough for not reducing the yields of crops nor creating environmental problems (e.g. salt contents).

Social implications and concerns on reuse or desalination vary from the acceptation of prices to religious reasons, or simply fears about the pathogen contents in reclaimed water.

In the case of reclamation, the actual research is focused on risk studies. Risk studies are undertaken on the basis of several quality parameters and are being developed considering what is called HACCP (Hazard Analysis and Critical Control Points). This risk tool, combined with the Good Reuse Practices concept, will allow the implementation of quality standards for reclaimed water that could be fit with a convenient cost.

Apart from studying rules and regulations, it is important to know which one is the real need of irrigation water. These studies could be based on the available water resources, the seasonal distribution of rain, or the need to create water distribution infrastructures. Some indicators could be used, like the water poverty index, the amount of water available per capita …

There are several differences all around the Mediterranean in terms of water availability, mainly between the North and the South; but specificities of the islands must be also considered. During the last decades, extensive technologies are being increasingly employed to guarantee good quality reclaimed water at comparatively low prices.

In which respects to desalination, technologies vary from membranes (mainly reverse osmosis or electrodialysis reversible - EDR) to evaporation procedures. The price of the desalination makes prohibitive the use of such water for irrigation, except in the cases of high revenue crops, golf courses or places where there is cheap energy, like the Gulf States or besides electricity generation facilities.

Runoff is collected in several countries, but the ways to use it can vary from one region to the other. In some of the islands still exist old cisterns, like in the Middle East regions. Nevertheless, this water is seldom used for irrigation purposes and is more dedicated to fulfil drinking water requirements, although there are several schemes considering a joint use of reclaimed water and runoff water for agricultural purposes.

WATER RESOURCES

The economic development is related with the availability of water resources, necessary to perform new industrial, agricultural or social (housing) developments. During the last decades, the water demand for recreational purposes (bathing, golf courses…) increased and is nowadays a small, but important part of the needs to be covered by the offer. The development increases usually the amount of people living in the area, as well as its welfare, which in turn increases water demands.

Usually, water demand for all the mentioned purposes, and especially for agriculture, is higher in the arid and semiarid areas because climate promotes the cultivation of vegetables and other plants if water is available. Then, the pressure on the existing water sources cannot usually be controlled and sometimes the result is a decrease in water quality due to overexploitation of surface waters (e.g. the dilution effects disappear) or groundwater (e.g. depletion of the water table or seawater intrusion). The recurrent droughts all around the Mediterranean even increase the problems associated to water scarcity.

It is to consider at this point the renewable resources available for each country. When this figure is low, there are more possibilities to develop desalination or wastewater reclamation (Fig. 1).

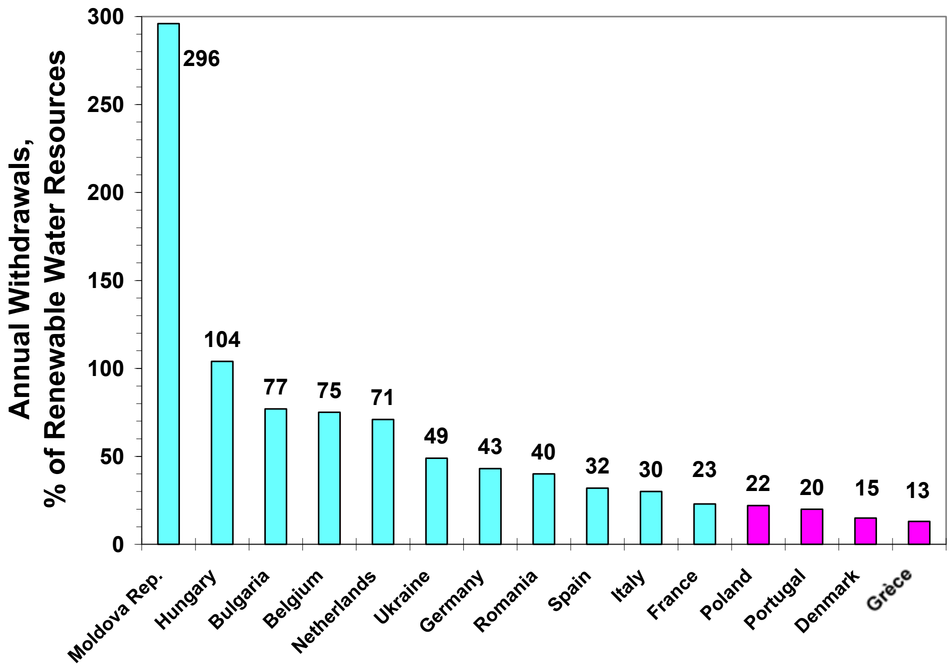

Figure 1. Renewable water resource exploitation in European countries (Angelakis *et al.*, 2003)

A consequence of the limitation of water resources is the development of tools to establish a ranking on water scarcity, called “water poverty index”. The subjacent statement is that water is a critical element of poverty in its many dimensions (Biltonen and Dalton, 2003). In response, there is a growing call to recognize guaranteed access to water for life (sanitation, hygiene and subsistence production). If there is a problem of water scarcity, several secondary considerations need to be made, mainly the ethical considerations related to maintaining environmental water requirements while people is starving or suffering water restrictions. Several tools can be developed to deal with this item, like the water stress indicator (Smakhtin *et al*., 2004).

The consequences of water scarcity are varied, but one of the main is the social negative impact, which in turn leads to discuss several uses, like the ones considered as sumptuary (e.g. golf course). Then, some of the activities that generate more revenues for the local population (e.g. golf or vegetable production) are compromised by the public opinion in grounds of an excessive use of the resources easily available.

Table 1. Water resources

Conventional	Surface water	Increasingly difficult to move water from the river: ecological pressure (minimal flows), denegation of infrastructures to transport water to other basins …
	Groundwater	Depletion and seawater intrusion are increasingly happening
Non-conventional	Runoff	Infrastructures to be built
	Reclaimed wastewater	Health risks associated
	Seawater desalinized	Price could be prohibitive
	Brackish water desalinized	Price could be prohibitive
	Non-conventional transportation	By ship or other (extremely expensive)

In which respects to desalination (brackish or seawater) the main concerns nowadays are the energy availability and the final price of the resource. An additional problem is the elimination of the refuse.

The possible planned reuse of reclaimed water has been developed considering the existing wastewater treatment facilities. Several consequences arise from that:

a) A reduction in the river flows, because the former untreated wastewater is no more disposed of into the river.
b) An improvement of water quality in the rivers and seaside, where untreated wastewater used to be disposed of.
c) An increase in the resources available.
d) An increase of the controls over the water; because reclaimed wastewater is measured and theoretically cannot be taken for free.

AGRICULTURE

All around the Mediterranean, the main water user is agriculture. When the resources are not enough to cover the demand, there are two solutions:

a) Increase the offer, and/or
b) Restrict the demand

It is difficult to increase the offer through conventional resources, because of the existing level of exploitation and because of social concerns. As pointed out before, the use of non-conventional resources could be one of the keys to solve the problem.

The other solution is to reduce the demand by:

a) Changing the types of crop. Using species or cultivars less demanding, the amount of water used can be reduced. e.g. do not cultivate corn.
b) Implementing technologies. e.g. using localized irrigation.
c) Applying the demand elasticity theory.

The first solution is not easy to perform, since it is an interventionist practice, difficult to implement. The second uses to be expensive, because of the material needed, and also difficult to apply, because of the possible soil salinization. It is also to say that crops incorporating more water (vegetables, watermelon…) are expensive and provide more revenues to the farmer. The third economic solution is the increase of the water price. If the water has high prices, then the inefficient operators are expulsed from the market. This is even more difficult to apply, because of the social implications for small farmers.

Then, the best solution seems to be the use of non-conventional resources (reclaimed water or desalinized water) which offers an additional amount of water.

The definition of non-conventional resource is simple: any resource different from conventional ones (Table 1). We will work from now on only with two types: reclaimed and desalinised salt/brackish water.

A point that could not be forgotten is the price for such resources. If we consider a theoretical water price, it must include all the costs incurred, from the extraction to the distribution to the end user. Then, reclamation or desalination will be included, not only the operation and maintenance but also the repayment (amortization) of the facilities. If the price is the real one, and not the politic one, then the resource becomes not available for many users. In any case, this is nowadays a policy of the European Union, to make disappear the subsidies for water.

Agriculture has in any case an advantage, which is the nearly total absence of wastewater, except for the tail waters, when excess water is used to control salinity, leaching the salts accumulated in the soil. Tail waters used and reused present due to the successive passages through soils heavy amounts of salt, leading to soil structure destruction in many areas all around the Mediterranean.

RECLAIMED WASTEWATER RESOURCE

Wastewater is generated in a continuous way; it is a theoretical reliable source of water. Water managers give priority to urban water before any other use, in some places even not considering the prices.

All around the Mediterranean basin, untreated wastewater has been reused for centuries mainly for agricultural purposes or indirectly for human consumption, when the mixture wastewater/river water is used for drinking. The result of this classical activity has been a spread of water related diseases. The knowledge of the hazards associated to this practice lead to:

a) The construction of sewerage systems in order to divert wastewater from urban settlements.
b) Lately, the construction of wastewater treatment facilities.

At the very beginning, the main purpose of wastewater treatment plants was the control of the diseases associated to raw wastewater. The hazard in this case derives from the possible contact water/person (includes ingestion). In a given moment of our recent water history, other considerations prevailed, and the main objective of the Sanitation Plants was to reduce the amount of Suspended Solids and Organic Matter from the raw wastewater in order to improve the quality of natural waters. In some way, this is a change of direction, from the anthropocentric to the ecological view.

Historically, wastewater has been an initially unused resource, located near the urban dwellings and somewhat continuous in cities. The temptation was extreme, and was even more considering that vegetables irrigated with raw wastewater have a perfect development and look really nice. This is the reason why, in most towns of the Mediterranean, Latin America or other places, vegetables to be sold in the market of the town are irrigated with the wastewater generated in the same place. Then, a circle is established where pathogens thrive perfectly, infecting and re-infecting the population. When a new disease arrives with a traveller, in a few days all the people is infected.

By this way, it became apparent that wastewater treatments capable to guarantee an acceptable risk are extremely needed. Other conditions are the economy of the process and the social acceptance of the resource.

BRACKISH/SEAWATER RESOURCE

In places where conventional water resources are not available or are fully exploited, usually in a non sustainable way, sometimes brackish or seawater is available within a reasonable distance. We must consider included here, brackish, seawater or brine (Sampol, 1999).

There are several technologies available, and the selection is made on the basis of the salinity level of the water to be treated. For brackish water is usual to employ EDR (Electrodyalisis Reversible), while for salinities close to seawater the most suitable technique is usually RO (Reverse Osmosis).

In this case, the limitation is due to the cost of water obtained. There is a considerable discussion on that price, because while technology manufacturers claim a price of 0.22 to 0.33 US dollars/m^3 (Efraty, 2001), scientists and stakeholders do not mainly accept this price. Shelef (2002) indicated a price of 0,70 to 0,80 US$/M^3 nearly at the same time and for the same process. In Spain (summer 2003) the water coming from a seawater desalination plant in Catalonia was being sold at a price of 0.38 €/m^3 without so much success, and not covering the full expenses.

The main advantage of such facilities is the availability, because seawater in the shoreline is unlimited and the brackish waters inland are not usually utilized.

An additional problem is the availability of electricity in the area where such facilities are to be installed; with huge energy consumption, electricity must be generated in situ or be transported with convenient lines which does not exist always.

In any case, the high price of this resource makes it unavailable for the common farmer or for the irrigation of common crops. Only the high cash crops (tomatoes, flowers, golf courses) can afford the use of desalinized water for irrigation.

TREATMENT TECHNOLOGIES

The two types of treatment described (reclamation and desalinization) share several common technologies, like the membrane ones; but for wastewater technologies not using too much energy are preferred, this is due to the fact that wastewater is usually employed for uses not really delicate, while desalination generated water to be used for drinking purposes or for high cash crops.

Membrane Technologies

Desalination technologies are usually used in islands or in places where there are not other resources available or the existing ones are overexploited, like in coastal areas. Occasionally, when no permission is allowed for the use of conventional resources (e.g. golf courses) or when there are crops with high value or demand, if the operation and maintenance is supported by the benefits. It is worth to note that in several parts of the Mediterranean, small farms are using such technologies to produce vegetables or fruits that will be sold at high prices in the northern European markets.

Usually, the technologies based in the use of membranes are cheaper than the ones based on evaporation, although it depends on the availability of energy at good prices. The membrane technologies mainly used nowadays are electrodyalisis, electrodyalisis reversible, and reverse osmosis (Sampol, 1999).

It is to note that several of the membrane technologies can disinfect perfectly the water, because the pathogenic microorganisms cannot pass through the membrane pores. The membrane technologies available for desalination and wastewater treatment are micro-, ultra-, and nanofiltration; reverse osmosis, electrodyalisis reversible, and electrodeionization (Deocón *et al.*, 2002).

Other Desalination Technologies

When not working with membranes, desalination relies on thermal processes which use a heat
When not working with membranes, desalination relies on thermal processes which use a heat source to evaporate water for a later condensation. Those processes are interesting when a source of residual heat is available (e.g. an electricity generating facility using combustion). Then, co-generation procedures can be employed. The thermal processes used for desalination (Sampol, 1999) are multieffect distillation, multistep distillation, distillation by steam compression, solar evaporation/condensation, and freezing.

The ionic exchange can be used for really specific purposes.

Filtration Technologies for Wastewater Reclamation

Apart from the natural systems which exert a filtration action (e.g. wetlands or infiltration-percolation) the classical filters (sand, monolayer or multilayer…) or the innovative ones (e.g. ring filters) can be used for reclamation purposes.

Intensive Reclamation Technologies

Apart from the membrane and filtration technologies, there are few processes more, like MBR (Membrane BioReactors) and occasionally SBR (Sequencing Batch Reactor) or RBC (Rotating Biological Contactors).

Apart from it, the physical-chemical systems using chemicals (polyelectrolytes and other), based on a coagulation-flocculation process, followed by sand or other media filtration, offer usually good results. A certain disinfecting action is exerted by those systems because bacteria and viruses are fixed to the eliminated suspended solids.

Extensive Reclamation Technologies

The infiltration-percolation, a batch natural system based in sand filters feed sequentially, offer good results, because they reduce to a minimum level the amount of suspended solids (below detection limit usually) and are capable to reduce more than 4 logs of *E. coli* or Faecal Coli forms. Apart from it, all N appears in the effluent as nitrates.

Lagooning is the classical system for obtaining reclaimed water relatively free of pathogens, provided a good hydraulic retention time is allowed. New developments applied to this classical system can greatly improve performances. The disinfection is guaranteed in the maturation pond by the UV natural radiation.

Constructed wetlands are also a promising technology, although the performances are not so good as the ones of lagooning and infiltration-percolation. Nevertheless, the integration of such facilities in the landscape is quite perfect.

Disinfection Technologies

Chlorination is not counselled for advanced wastewater treatment because of the quantity of by products generated and the toxicity for aquatic wildlife of the chlorine. In any case, dechlorination must be used after the treatment.

The use of ozone is a promising technology if properly used with wastewater; it acts mainly against bacteria and viruses (chlorine does not affect so much the viruses), reduces odours, does not generate additional waste solids and increases the oxygen content of the effluent. If the organic matter content is important, the doses needed for obtaining good disinfection are comparatively high.

Chlorine dioxide use is considered as a good alternative for conventional chlorination. It is a good oxidant, used especially in water containing phenols and it eliminates odours. However, its main disadvantage is the reaction capacity with a lot of compounds and ions like iron, manganese, nitrite ... It does not react with ammonia or with bromine. It must be generated in situ and does not cause by-products generation in appreciable amounts. It is considered as a good biocide and affects also algae.

UV is a technology experiencing nowadays a good development. It is based in the effectiveness of the 253.7nm wavelength radiation against bacteria and viruses, and the new developments (medium intensity, pulsed…) can exert an action against *Giardia* and *Cryptosporidium*. Low-pressure lamps are the ones mainly used for wastewater disinfection.

ECONOMY

The real cost of water resources production from salt-containing waters or wastewater is the result of considering the amortization, technical and financial, operation and maintenance costs, chemicals, electricity and personnel in relation with the production. It is not to forget the raw water supply and the elimination of the brine.

It is worth to say that the same thermal technology can have different costs depending on the physical location of the facility (e.g. distance from the sea, energy supply…), subsidies, co-generation, and others (Sampol, 1999).

Discussions arise when dealing with:

a) The real price of desalination technologies.
b) Who will pay for desalination or reclamation when water is used for agricultural purposes, in crops with low revenues?
c) Which quality is to be demanded for reclaimed wastewater, and who will pay for the analytical costs?

RISK ASSESSMENT AND MANAGEMENT IN WASTEWATER REUSE

Given the wastewater characteristics and the treatment technologies requirements by the existing laws (e.g. EU Directive 91/271), it is worth to say that there is an important pathogenic reduction in the secondary treatment, which is improved when applying tertiary technologies or more specifically disinfection. Nevertheless, an important amount of chemicals still remains in treated wastewater, capable to generate several hazards.

It seems then that a risk management approach could be undertaken to ensure a correct application of reclaimed wastewater. Given the relationship among the crops and the consumers (direct ingestion), this approach can be undertaken from several points of view. The first one is the use of standards to guarantee a certain quality of reclaimed water. Apart from the parameters, other tools, like the use of Good Reuse Practices or a Hazard Analysis and Critical Control Points (HACCP) system should also be implemented (Salgot and Angelakis, 2001).

Nowadays, there are known technologies for wastewater treatment. However, not all the technologies are useful for all locations. The BAT (Best Available Technology) methodology, which takes into account all aspects of the decision related to the specific site is to be employed.

The degree of compliance with the standards over long periods of time is to be studied, although usually there are not enough data and this is one of the weak points of the reclamation processes.

The HACCP system is to determine the specific points where analyses are most useful. It is nonsense to determine the reclaimed water quality at the end of the treatment chain and not to do it in the point of use.

There are several research items in the field of risk assessment and management of reuse (Salgot *et al.*, 2003). We can mention among them:

- Use of adequate control parameters,
- Reliability of reclamation plants,
- Standards compliance,
- Good reuse practices of the reclaimed wastewater,
- HACCP systems.

It should be indicated that the risk assessment and management use do not reduce *per se* the risk associated to reclamation and reuse, but allows a better knowledge of both practices with wastewater and, as a consequence, it can allow the implementation of techniques in order to reduce such risk.

THE RELATIONSHIP BETWEEN NON-CONVENTIONAL WATER RESOURCES AND THE AGRICULTURE IN THE MEDITERRANEAN

There is need to establish the relationship between water availability, its quality, and agriculture. This approach is by no means new, but two new players are entering in the field, the reclaimed wastewater and the desalinated water.

The situation used to be the following:

a) When plenty of water is available, crops are irrigated with high amounts of water, even in excess above the requirements of the plant. In the Mediterranean, this situation is not much common, but can be found in the deltas and in the vicinity of the rivers. Ridge and furrow or simply inundation are the common irrigation methods. No “technification” exists.
b) If the water is expensive, or starts to be scarce, because of the lack of resources or because of legal constraints, policies of water savings (i.e. reduce the demand) can appear, spraying or localised irrigation are employed in considerable surfaces; the use of non-conventional resources starts to be considered.
c) In areas where water is not available at all, or the resources are overexploited, there are several possibilities:
    i. If economic capacity exists, and also brackish or seawater, desalination technologies emerge.

ii. If wastewater is available, it is used. Wastewater reused can be reclaimed or not, depending also on the economic capacity or the subventions.
iii. If there is no economic capacity nor wastewater, subsistence agriculture is developed.
iv. Non-conventional cultivation procedures can appear; e.g. rain farms.

In the Mediterranean, there is a combination of all the mentioned characteristics and a movement of agricultural products can be stated form the South to the North of Europe (oranges, tomatoes, watermelons…). In addition, from the North of Africa to Europe, there is exportation of agricultural crops, like tomatoes and oranges. Tunisia and Morocco are very active in this field.

It is paradoxical that countries with water scarcity export crops with extremely high contents of water to the water rich countries such as the North of Europe.

Water used for irrigation in the Mediterranean basin can be:
a) Water diverted from rivers (Nile, Ebro, Rhône…).
b) Raw wastewater (quite in all countries are examples).
c) Reclaimed wastewater (Tunisia, South of Italy, Greece, Spain, South of France, Israel…).
d) Groundwater (Algeria, Italy, Spain, Israel…).
e) Desalinated water (EDR or RO) for high rewarding crops in specific sites (e.g. Southeast of Spain, Canary Islands).

It is extremely difficult to indicate which proportion of each is used, because local circumstances change a lot and a pattern cannot be found.

The most technologically advanced country is Israel, a big producer of irrigation material, and where localized irrigation (surface and subsurface) and reclaimed wastewater irrigation have been developed since the fifties of the 20th century and are fully employed.

There are efforts in other countries to change irrigation patterns, in order to reduce water consumption, e.g. substitute ridge and furrow by localised irrigation, use of computer programmes…

Although governments have been for decades announcing its support to the use of non-conventional resources, mainly legal wastewater recycling, the reality is different.

Desalination is a common practice in the small and medium Mediterranean islands, but not so much in mainland and big islands (Crete, Sicily).

Reclaimed wastewater reuse is not fully expanded in the Mediterranean, but in Israel – the whole country – and counted specific locations in the other countries. This is true, despite the promises and indications by the Governments.

CONCLUSIONS

It is necessary to change the Mediterranean agricultural patterns of water use, moving to more technical agriculture.

The types of crops being cultivated are to be revised, in grounds of the amounts of water they are consuming and the benefits produced.

Non-conventional resources are to be promoted and fully integrated in the water global management.

Desalinated saline water could be very expansive, and only high cash crops can afford its use.

Reclaimed wastewater can increase the amounts of water available for the agriculture, but up to now this practice is not fully implemented.

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