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Non-conventional water resources in coastal areas: a review on the use of reclaimed water

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ABSTRACT

In an era of increasing concern for limited water resources a wise joint management of conventional and non-conventional water resources must be considered. Water scarcity aggravates in coastal zones which are often characterised by high population density, intense economic activity and tourism; meaning heavy seasonal water demands. The relationships between sea and land-water can also compromise the quality of available freshwater. In this context, the use of non-conventional water increases the availability of water supplies. Non-conventional water resources of low quality could be directed to meet several needs (like watering lawns, washing cars, flushing toilets and cooling systems, among others). Therefore, significantly more potable water would be available to meet human demand for safe water.

KEYWORDS | Water resources. Coastal areas. Non-conventional water. Water reclamation. Desalination. Waste water reuse.

INTRODUCTION

Water demand in coastal areas is increasing because of population growth, industry, agriculture, and tourism development in this limited portion of the emerged lands. The objective of this paper is to review the possibilities of increasing the water resources available, especially reclaimed wastewater. Population has a strong tendency towards inhabiting coastal areas for several reasons; among them, a mildest climate if compared with mainland, important economic activities related to transportation facilities, and other benefits which include landscape aesthetics, building purposes, access to bathing waters, and the like. Also, due to the easiness of transport by ship, road or railway, a lot of industries are mainly located near harbours.

Among the richest agricultural lands, deltaic and similar areas occupy a prominent place. Vegetables, rice, corn, and other high-income crops can be grown in such areas, using at the same time huge amounts of water. Citrus and other orchards need also to be located in the vicinity of the sea or places with mild climate.

When translating all these activities in terms of water demand, we notice a concentration in time and space; in most cases the demand increases extremely during summertime and within a fringe of a few kilometres from the sea towards mainland. The usual way to cope with is through the use of conventional water resources, namely surface and groundwater. Since surface waters are not evenly distributed all along the coastline and groundwater resources are limited, the offer must be increased through water transportation infrastructures or by using non-conventional resources. A classification of the different types of water resources when considering their origin can be found

TABLE 1 | **Classification of water resources depending on the origin.**

Inside the basin		External to the basin*
Conventional	**Non conventional**	
Surface water Groundwater	Continental brackish water Seawater Runoff Reclaimed wastewater Dew, frost	Classical transfers among basins Other transfers (ship, railway…)

***The classification among conventional and non-conventional can also be performed here, if necessary.**

in Table 1, whereas the possible uses of water developed society are shown in Table 2.

Although it seems that a balance between demand and offer should be obtained by increasing the offer, the most sustainable way to do it is through the implementation of saving measures. It means sometimes a reduction in the demand by the way of increasing efficiency for use, or a reduction in the extractions of conventional water resources, possible by using non-conventional water resources.

Conventional resources

In coastal arid and semi-arid climate locations, surface waters (streams and lakes) can offer a limited amount of the resources required by agriculture and tourism. This is due to an uneven location of rivers, a lack of streams in islands, a coincidence of low flows with peak demands, and other factors. Groundwater can sometimes offer a limited water supply, because of the need to maintain a water barrier to control seawater intrusion.

New conventional resources can be obtained through infrastructures for water transfer from other basins. Nevertheless, this solution becomes more and more difficult to implement because of an increasing scarcity of basins acknowledging an excess of water resource, non-acceptation from donor areas, or financial limitations.

Non-conventional water resources

As indicated before, when conventional water resources reach a limit, additional supplies can be obtained from other water sources, mainly non-conventional ones, which include seawater and brackish water desalination, runoff water, and reclaimed wastewater. Other possibilities are transportation by trucks, railway or ships.

Socio-economic features are to be considered a key issue for the possibility of implementing such alternatives. Cost (transportation), energy demand, availability (desalting), and wastewater reclamation and reuse capabilities are the limiting factor for those cases.

Water balance

From the viewpoint of balancing offer and demand of water, an excess of demand can be dealt with either by increasing offer or by limiting demand. Offer increase will not create a balance, because there is a false sensation that authorities will facilitate an ever increasing amount of water, which is by definition impossible (Van de Ven, 1990).

From the demand side, water authorities can act over price (increasing prices, which are in relation to what is called “demand elasticity”) or by educating people on the reduction of water demand, through the use of water saving devices or by education campaigns (Griffin, 2001). In any case, it seems that the main water reductions can be obtained in agriculture, since this activity is the main water consumer in arid and semiarid climates. Industry in developed countries can be easily convinced to reduce water use through pricing and other easily implemented measures, while savings in domestic/urban demand are practicable only in specific cases: improvement of distribution networks, installing in-house devices, and the like. In the case of Barcelona the modernization of the system accounts for a reduction from 30% in the losses to around 10%. Most large cities in the world have losses from 20% over.

Coastline specificities

Because water consuming activities in the coastline are usually located at the end of basins, there is almost always an association of scarce flows (in relation to demand) with poor quality of the flowing water, because of upstream uses. Apart from it, it becomes difficult in the coastline to build water storage facilities near the points of use. There is a tendency to cope with demand by first using surface waters (easy to obtain from the physical and economic aspects) and using groundwater afterwards, especially when peak demands are to be covered. Nevertheless, a lack of planning procedures for water extraction is usual in these cases, even if existing resources can cover the demand easily. Planning efforts commonly start when drought or scarcity starts to appear.

Water resources and wastewater need to be conveyed to the point of use or to the point of treatment/disposal. As the territory is usually fully occupied along the coastline, the only space usually free to install infrastructures is the shoreline. It is common to find water transport infrastructures (pipelines, channels) along the beaches, both for tap water and for sanitation.

Regarding the impact of agriculture, as irrigation water needs to be applied in excess of crop demands, infiltration or irrigation tails are nearly always heavily loaded with salts, nutrients, and pesticides. Thus, a negative impact on existing water resources, either groundwater or surface water (diffuse pollution), and occasionally seawater if the agricultural area is located in the vicinity of the shoreline, is generated.

Sewerage facilities in the coastline present additional problems because of the relationships with seawater. Seawater can enter sewers through discontinuities or through old outfalls. Tides or strong winds have the same effect: seawater enters into old sewers purposely or inadvertently not closed. Building activities in the shoreline tend to pump water (mainly seawater under the sand) and dispose it into the sewerage.

When groundwater is pumped out in excess in coastal aquifers, the consequence is seawater intrusion (Custodio and Bruggeman, 1987). This situation became classical in locations with water stresses all over the world. In the recent years, several solutions have been proposed, ranging from an integrated management of aquifers to groundwater recharge using reclaimed wastewater. It is not to forget that aquifers can play a key role for water storage in coastal areas, when it is impossible to build surface storage infrastructures near the coastline due to the inexistence of suitable locations.

Water uses in coastal areas normally show an uneven pattern all along the year. Peak demands from different users (agriculture, tourism, all year-round and seasonal inhabitants) tend to concentrate during summer months, thus exerting a strong pressure on water distribution facilities and on water authorities. It could become necessary to satisfy demands from users in different sites, if they own two or more permanent or temporal residences in coastal areas in the same country or in different ones.

Urbanisation of the coastline (resorts, cities, industries, surface and underground urban infrastructures) creates a barrier for the circulation of natural waters in three different ways. The first one is related to "non-natural structures" for groundwater circulation from mainland to the sea; underground railway, roads, etc., which can also create artificial barriers. The second one is the implementation of infrastructures that prevent surface water circulation (tall and extended buildings, urbanisation of inundation areas and wetlands liable to be flooded) or which occupy river and small stream beds. The third is the occupation of the terrain with impervious structures (parking lots, buildings, streets, etc.) which affect infiltration. Then, groundwater and surface flows are reduced, and the normal circulation of water is not allowed, creating a different water flow model in the interface land-sea, which can extend to thousands of meters inland. It needs to be managed if abnormal events or natural hazards occur. The so-called "geohazards" can appear and generate what is called "natural disasters"; they are to some extent facilitated by human infrastructures (Coch, 1995). At the same time, structures can act as drains reducing groundwater levels.

As a result, used water (wastewater) from industries and towns, and runoff water has to be evacuated usually to the sea, because there are no other solutions except reuse. Submarine outfalls are the classical solution for wastewater, but stormwater needs different solutions. Urban runoff is in some way cleaning all town, from streets to sewerage systems, including roofs and other impervious surfaces. Since there are no infiltration possibilities, such water only reaches the sewerage if combined systems are implemented or if separate sewerage exists for the drainage of rainwater (Metcalf and Eddy, 2003).

In case of heavy rains, rainwater reaches seawater along the coastline through sewer overflow devices or by surface runoff, thus polluting seawater. It results in pollution of bathing areas during several days or hours (depending on the tides and currents). The problems are due not only to faecal contamination, but to suspended solids as well. They can include dead rats, huge suspended solids, and the like. Apart from the aesthetic problems, health related risks appear during some time, depending on the local currents and other water movements.

It is not to forget the existence of harbours and marinas in the coastal environment. Those facilities can exert a certain influence through the dissemination of wastewater and loss of paints and other chemicals from ships. Then, neighbouring systems (bathing water, sand) become heavily contaminated, but the contamination is not from land ongin.

TABLE 2 | **Possible uses of water, observations for quality and resources adequate for the defined use.**

Type of use	Specific use	Observations	Useful resource
Urban domestic potable	Drinking Hygiene Cooking/food-related	Maximum quality (suitable for drinking purposes)	Conventional Occasionally reclaimed wastewater (if there are no other possibilities) with or without blending
Urban commercial	Drinking, cooking and hygiene in hotels, restaurants, and similar		
Urban fountains	Drinking		
Urban "general" not for drinking, but related to domestic	Air conditioning	Disinfected, especially for *Legionella*	Conventional and non-conventional
	Toilet flushing	Disinfected	Conventional and non-conventional
Urban not domestic	Fire protection Irrigation of public spaces Irrigation of private spaces Urban cleaning (streets…)	Disinfected	Conventional and non-conventional
	Sewerage management	Secondary treatment if wastewater	Non-conventional if possible
Industry	Food-related Pharmaceuticals and similar	Tap-water quality	Conventional
	Cooling water* Boiler feed Process water Heavy construction	Constituents related to scaling, corrosion, biological growth, and fouling to be controlled. * Disinfection for *Legionella*	Conventional and non-conventional
Agriculture	Food crops Non-food crops	For reclaimed wastewater: rules or regulations. River water and freshwater usually do not have quality-related rules.	Conventional and non-conventional
	Aquaculture	Specific rules (WHO)	
Non-agricultural irrigation	Golf course irrigation Landscape Forest	For reclaimed wastewater as indicated by rules or regulations. Freshwater usually does not have quality-related rules.	Some countries are forcing these facilities to use only non-conventional resources Conventional and non-conventional
Livestock	Watering and dairy operations	Should be potable	Conventional mainly, and non-conventional other than reclaimed water
	Fish farming	Specific rules (WHO) for the use of reclaimed water	Conventional and non-conventional
Groundwater recharge	Direct recharge	Advanced tertiary treatment if wastewater Pre-potable if other source	Conventional and non-conventional
	Indirect recharge	Through soil formations	
Water-related sports, leisure activities	Contact allowed Contact not allowed Snowmaking Leisure boats maintenance	Specific rules and regulations if reclaimed wastewater is used	Conventional and non-conventional
Stream and water bodies recharge	Habitat wetlands Lakes and ponds Enhancement of marsh and similar Streamflow augmentation	Toxicity for aquatic and water-related wildlife	Conventional and non-conventional
Thermoelectric power use	Power generation	No need of quality rules, but resources management is essential	Usually conventional, but stream augmentation with reclaimed wastewater is possible

NON-CONVENTIONAL WATER RESOURCES

Because new conventional resources are not usually available to cover excess or peak demands for several reasons, non-conventional resources are to be employed. Among these non-conventional water resources several possibilities are to be considered, but the usual ones are runoff water, brackish water, or desalinated seawater (Georgopoulou et al., 2001). Non-conventional water resources, coming from the anthropic water cycle can also be used. We refer mainly to reclaimed wastewater (Asano and Levin, 1998).

Runoff water

In the Mediterranean basin, a lot, of river beds carry water only after rain events; this is due to the small size of coastal basins, to the imperviousness of important parts of the basin, or on the contrary, because river beds are often dry in high permeability areas, like karstic zones. Due to the disappearance of the coastal lagoons, marsh and wetlands (the natural ways to control excess flows), and sometimes to the transformation of the free-flowing streams in pipeline systems, there is an increase in the quantity of localised (streambed) water flows per unit time. Because the flows are concentrated in time and there is no recharge, they can be used to increase water supplies if appropriated treatments can be performed. This is the case in Palma de Mallorca (Balearic Islands), where occasional runoff is collected, treated and distributed as tap water for the city (Terrassa and Cadenas, 2000). There is an economic consideration here; is it worth to build treatment infrastructures for a scarce amount of resources? The answer is not easy and demands good economic calculations.

When there is enough space to install constructed wetlands using marginal lands or areas without any specific use (motorway medians or surroundings), rainwater can be diverted to such areas until it percolates and recharges groundwater using the soil/subsoil system (vadose zone) for additional treatment. In other cases, small or medium sized storage pools or dams can be used to retain such waters if enough space is available.

Desalinated water/desalination

If there is not other water available, there is always the possibility of using water containing high amounts of salts. The salt contents can be eliminated using several technologies, but mainly membrane related techniques (Medina, 2000). Apart from evaporation, which consumes excessive amounts of energy for the Mediterranean standards, Reverse Osmosis (RO) and Electrodialysis Reversal (EDR) are being used nowadays. RO is preferred when using seawater as affluent, while for salt contents up to 10 g/L EDR seems to be the best technology. As the price for desalting water could exert a strong influence in the election of the technology, support decision systems (DSS) are to be employed in order to choose the best adapted system.

Water coming from RO cannot be used directly; it needs to be mixed with other water containing salts. The RO water can be assimilated to distilled water, which is not adequate for direct human consumption or for irrigation. There is an additional problem in relation with RO and other desalting technologies, which is the salt generated during the separation processes. If salt is in a solid state the problem is not so complex; nevertheless, the brine generated by EDR or RO must be disposed of. The usual destination has been the sea, through outfalls, but there is an increasing concern on the impact of such brines in the sea, because it seems that *Posidonia* and other components of the marine ecosystems suffer from excess of salts.

Reclaimed wastewater

Reclaimed wastewater is the most used non-conventional water resource. As wastewater reclamation and reuse has been studied extensively since the 1920's, and great amounts of treated wastewater are usually available at the coastline, reclaimed wastewater is to be fully studied and employed in the coastal areas. A whole section of this study will be devoted to this topic.

Other non-conventional resources

Since the classifications are really difficult to implement, we can quote as non-conventional water transported through non-classical methods (ship, railway, etc.), water obtained from condensation, etc. Usually, these resources will not offer significant amounts of additional water and are only useful for specific situations.

RELATIONSHIPS BETWEEN SEA AND LAND WATERS

In the seashore, continental water and seawater are located in a physical system which exerts an influence in the exchange of water between the two systems. At the same time, water, especially through its movements, modifies the physical characteristics of the coastline. This topic will not be covered here in detail, but it is to be considered because water quality modifications can occur due to water movements in this specific area of study. From now on we will consider only the water-related aspects in the coastal interfaces.

Coastal water interfaces

The coastal area has several interfaces among land, epicontinental water, groundwater and seawater. The main goal in any case should be to maintain seawater in the sea, while trying to lose a minimum amount of continental water to the sea. Although this is the main idea, it is not to forget that there could be negative impacts if the separation mentioned above is fully performed. The good state of beaches partly depends on the sand and other materials brought by rivers and streams to the sea, and in some way sea fertility depends on the nutrients coming from emerged lands. A steady state is to be reached, and in some way managed, although there is a lack of knowledge in many of the aspects affecting this process.

Several flows can be considered in the interface coastline-sea, namely a) natural water flow into the sea; permanent (rivers) or temporary (non-continuous streams, direct runoff into the sea); b) seawater entering streambeds (e.g. in periods of low flow in deltaic areas or in estuaries at low tides); c) anthropic water flow into the sea: through outflows carrying treated or untreated wastewater, rainwater, refuse water from reverse osmosis systems, cold water from electricity generation facilities, wastewater from boats and ships, etc.; d) flows in and out of several natural structures (coastal lagoons, marshes, etc.); e) drainage systems from land into the sea, such as those from agricultural lands.

When there is an exchange of water between the sea and land, there are two possible types of changes; physical-chemical and biological. It is also to take into account that the relationships can be considered in two ways; sea-land and land-sea. In the first case freshwater enters into a salty environment and in the second one salty water enters into freshwater media.

Physical-chemical relationships

The physical-chemical relationships between freshwater and seawater along the coastline can be described in the open water (sea) as:

- Mixtures: when both waters are mixed and finally freshwater is diluted into seawater. It usually happens in Mediterranean-type seas, where rivers and streams reach the seaside in delta formations

- Stratifications: when several layers of saline and freshwater can be found. It usually happens in estuaries, like the Atlantic interfaces with rivers. The strata can persist for days and even weeks until forces that guarantee a whole mixture appear. This situation can help saltwater to travel upstream to the river bed.

The mixture salt/freshwater can be improved and happens quicker if there are strong winds (and consequently strong waves) and high tides.

Salt can also enter land underground through seawater intrusion into aquifers, in addition to mixing in the surface as indicated before (estuaries) or when Mediterranean-type rivers have low flows, seawater does not find the freshwater barrier and can travel upland through the river bed. Due to the contact between river and aquifer, the latter can become salinised. This phenomenon can be exacerbated when rivers are regulated and do not have periodic floods, wich clean the entire system.

As indicated, water in coastal areas has a strong relationship with salts:

a) Salt from seawater can enter groundwater if marine intrusion into the aquifers occurs, either naturally or by human intervention, i.e. extracting too much water from coastal aquifers.

b) Groundwater carries salts infiltrated together with excess irrigation water.

c) Seawater can enter the sewerage system. It can occur because winds or tides can raise the seawater level in relation to sewerage system outputs or press water into the outfalls. In sandy areas, it happens that the sewers are built into the beach; then, when there is a breakdown; seawater passes through sand and enters directly into the pipes.

d) Salty water from swimming pools, showers, etc. can increase the usual amounts of salts in wastewater coming from urban uses.

e) Waters transported from other basins can have different salt contents.

As sewerage systems in tourist areas are compulsorily built for the maximum flow/peak seasons (i.e. summertime or weekends during the non-peak seasons), and because the sewers are usually empty and many have cracks if built on sand, it is easy that seawater enters the sewerage system.

If the entries of salty water into the sewerage systems are casual (i.e. in a non-continuous way), the reliability of the wastewater treatment facility is seriously compromised. On the contrary, if salty water enters in a continuous way, the microbial culture gets used to the normal salt contents and the system becomes reliable, although the quality of the water may not be suitable for several types of reuse.

When wastewater reuse is introduced into this system, the available amount of water increases, but salt content may also increase. If salt contents increases, the solution could be: a) an integrated management of the whole system: the management differs in every type of area, from deltas to cliffs, where aquifers meet the sea. It is to say that rivers are usually associated to aquifers in the coastline; b) the creation of artificial barriers to limit seawater intrusion. It can be done using reclaimed wastewater; c) the improvement of structures related.

Biological relationships

Usually, the biological incidence in coastal waters is only in one direction, land to sea. As epicontinental waters usually have a content of microorganisms from faecal and soil origin, the arrival of continental waters into the sea may cause the presence of pathogenic organisms in the seawater.

As the presence of pathogens in waters is hardly detectable because of analytical and economic constraints, valuable indicators are to be searched (Campos, 1999). For fresh water, the most used indicators are the coliforms, either total or faecal, or directly *E. coli*. It seems that for water containing salts, *E. coli* or coliforms are not the most adapted indicators, and others are suggested, such as faecal streptococci, *Staphylococcus aureus* or *Clostridium*.

Groundwater has not an important bacterial flora, because of the prevailing conditions in the aquifers. Theoretically, pathogens could not survive for a long time in that environment; nevertheless, there are descriptions of long residence times of viable bacteria and viruses in soil and groundwater (Campos et al., 2000).

It is to state that coliform counts in seawater generate a lot of discussions. Theoretically, there is a good decay of these bacteria, and it is to consider if there is a continuous feeding of such bacteria through arrivals from land, or if the count is generated by a single entrance of polluted water. A clear relationship should be established with the presence of outfalls, flows from the land, etc. in order to have good interpretations of results (Blumenthal et al., 2000).

Faecal coliforms, which are the organisms conventionally used as faecal pollution pathfinders, do not fit all the requirements to be considered an ideal indicator and show some limitations. To overcome these limitations some authors have proposed the use of bacteriophage as faecal pollution pathfinders and especially of viral pollution (Alcalde et al., 2002). Bacteriophages, also called phages, are viruses that use bacteria as host cells for their replication. In terms of size, morphology, structure, composition and mode of replication, some phages are similar to the human enteric viruses. At present the bacteriophages mostly used as faecal pollution indicators are somatic coliphages, F-specific bacteriophages and bacteriophages of *Bacteroides fragilis*.

Apart from the presence of pathogens, water flowing from land causes an input of nutrients into seawater. It can generate a richer environment, which favours the growth of algae, and consequently accelerates the trophic chain. It means that, in the vicinity of outflows, a higher productivity is attained. Algae usually thrive in such areas, and in closed seas or sea parts, eutrophication phenomena can be described. Sometimes, the algae that grow in such areas can generate toxins, capable to be accumulated in shellfish and cause toxicity episodes.

Coastal bathing/leisure water

There is a need to establish water quality criteria for bathing areas near the coastline. This is done at European level and there is a discussion (as it is in wastewater reuse for agriculture) on the coliform levels.

Standards are issued taking into account two types of contact between man and wastewater while bathing in seawater: contact with skin and mucous membranes, and ingestion. Near the sea, swimming pools can be filled with seawater, which needs special managements and controls, different than the ones in the systems which use freshwater.

Aquatic parks and diving are also activities in relation with seawater in the coastline and specific measures should be taken to guarantee the safe use of water for such purposes.

Other economic activities in the coastline

Apart from tourism, there is the possibility to develop other economic activities in the coastline. Perhaps the main one is shellfish and fish capture and breeding. This type of aquaculture generates good revenues but is extremely sensitive to pollution derived from the presence of wastewater in the media where they grow.

Due to specific characteristics of shellfish (cultivated or not) it is to say that water must have a good quality. Shellfish filter water to obtain food. It means that if organic matter contains bacteria or viruses, those organisms concentrate in the flesh of the shellfish to be eaten, often raw, thus generating a high risk of water related illnesses.

Specific measures have to be implemented, meaning that water coming from the land must not enter directly the lagoons or open sea where shellfish is growing. Additionally, wastewater treatment systems must perform well and effluents must also be disinfected in the majority of cases (Angelakis and Bontoux, 2001).

In coastal areas, there is an extra need for water due to the demands for tourism; green areas (landscaping), golf courses, and similar facilities require high quantities of water for irrigation. This type of irrigation differs from the classical agricultural irrigation; it is more controlled and not devoted to agricultural production.

When trying to attract high-income tourism, water availability is an important factor for development. Often, additional amounts of water are needed to cover such demands. This adds pressure to the balance demand/offer and is another reason to search for additional resources.

WASTEWATER RECLAMATION AND REUSE

Wastewater to be reclaimed is generated mainly in domestic uses, with some addition of industry generated liquid waste. Nowadays, industrial wastewater is mainly separated from urban wastewater or undergoes a pre-treatment which eliminates any harmful component. Then, the whole flow can be usually assimilated to domestic wastewater. As the EU Directive (91/271) on wastewater is theoretically implemented, in the European coastlines wastewater related impacts are reduced to a certain acceptable level. In practice, several towns still need to improve its wastewater treatment. In any case, we can state that huge amounts of potentially useful treated wastewater are disposed into the sea, and they could be reused.

As water is used for many purposes in developed society (Table 2), it is to consider which ones of these uses can be satisfied with reclaimed wastewater. Theoretically all uses can have reclaimed wastewater as a source. Nevertheless, several of them are usually discarded (e.g. potable uses) although there is a description of reclaimed wastewater being used for tap water, in Windhoek, capital town of Namibia (Odendaal et al., 1998) for many years.

All over the world, the main reclaimed wastewater use is in agriculture. Due to the fact that the main production of wastewater is in towns and big cities, there is reclaimed water in excess near towns. If this water is needed in the country, there are two main solutions, namely: a) transportation from the production area to the places where it can be used; b) the search for uses other than agricultural ones.

In the first case, there is the need to build a network for transportation and final distribution. The classical example can be found in Israel, where reclaimed wastewater from Tel Aviv area is conveyed through a water carrier to the Negev desert (Cikurel et al., 2001).

The second case is being developed through the use of reclaimed water in town or in the coastal areas, for uses such as urban parks and gardens or groundwater recharge. Industries in the coastline can also rely on reclaimed wastewater.

If we consider additional uses, as indicated in Table 2, we can describe, in relation with the coastline, stream flow augmentation and landscape related uses.

Risk related aspects

When reusing reclaimed wastewater it seems obvious that a risk will appear (Salgot et al., 2003). The risk is, in all cases, due to the presence in the reclaimed wastewater of contaminants: pathogens and chemicals. Pathogens include protozoa, bacteria and viruses (Campos, 1999), whereas chemicals range from the simplest ones (e.g., nitrates) to the more complex molecules, e.g. THM (Crook, 1996).

Pathogens usually generate infectious illnesses that can or cannot be apparent (clinical and non-clinical) and appear in the short term. When chemicals are related to toxicity, the illnesses are acute or long-term. It is obvious that the better the reclaimed water quality is, the less the risk. When dealing with risk, two steps are to be considered: assessment and management. It seems basic to have a guide on how to assess the risk. Nevertheless, this type of guide does not exist in full and is nowadays an object of intensive research (Salgot and Pascual, 1996).

Several tools are being developed and start being available for the assessment. The most known one is the system known as HACCP (Hazard Analysis and Critical Control Points). This system, developed for foodstuff industry, focuses on the identification of relevant control points. The implementation of these control points increases safety while reducing the costs through a better use of analytical work. HACCP is to be conducted considering seven main points as indicated in Table 3.

HACCP procedures must theoretically be performed for all programmed reuses. In specific cases, as for bathing water or shellfish cultivation, it is necessary to establish contacts with Authorities implicated, e.g. Health Departments. In any case, the risk is related to the presence of a contact between the target (man, animals, plants) and reclaimed wastewater.

The solutions to reduce risk are: a) a reduction of the possible contacts between the pathogen and the target organism, and b) a good reclaimed water quality.

a) It could be reached through what is called good reuse practices, intended to reduce the possible contacts. While considering that “contact” in a broad sense could imply either direct contact, i.e. skin or mucous membranes contact, aerosols entering the respiratory tract, etc., or indirect (clothes), any contact reduction will imply risk reduction.

TABLE 3 | **Main points to be developed in Hazard Analysis and Critical Control Points (HACCP) systems.**

Item	Observations
1. Conduct a hazard analysis	Needs to be developed for wastewater treatment and reclamation facilities.
2. Identify the CCP (Critical Control Points)	Not clearly defined if it should be in the entire wastewater management (i.e. from the point of wastewater generation to the point of use and beyond, e.g. fate of generated products like vegetables).
3. Establish target levels and tolerances	It is extremely important not to set only the percentage of samples that are allowed not to comply, but also the tolerances (maximum deviation allowed).
4. Establish a monitoring system	Needs to be issued taking into consideration the analytical capacity (e.g. complex chemicals) and the cost of the whole control procedure.
5. Establish the corrective actions	When problems are detected and all the information is available, corrective actions should be implemented. In the meantime it is to consider if the facility has to be stopped and reclaimed wastewater is not to be delivered.
6. Establish documentation	Necessary to identify all problems during the lifespan of the project.
7. Establish verification procedures	The whole procedure must be analysed in a continuous and periodic way.

b) This is obtained using standards, which when enforced must guarantee a quality of water theoretically good enough to reduce the risk down to an acceptable level.

The role of reclaimed wastewater in the coastal environment

The main idea when trying to improve water status in the coastline environment, in all cases, is to introduce new water resources. This water can reach the environment through streams, recharge or irrigation. When there is no other water available in acceptable amounts than reclaimed water or desalinated water, the management of additional resources is to be carefully considered (Van der Hoek et al., 1999).

Desalinated water must not, in normal circumstances, be disposed of in the environment, because of its cost and quality. It is directly (usually with a previous mixture) introduced into the tap water distribution system, or occasionally used for agricultural purposes if the crop generates enough profits for assuming the cost of desalination (this is the case, for example, of tomatoes, watermelons and other vegetables collected in wintertime).

As indicated in Table 2, the main reclamation purposes which imply a distribution of reclaimed water in the environment (especially in the coastline) are:

Irrigation

Through irrigation, there is an increase of water entering the soil-plant system. It means increases in evapotranspiration and infiltration in the area. Water may be applied in excess of plant needs in order to leach the salts remaining in the soil. In this manner, water reaching the aquifer can increase the salt content of the groundwater (including nitrates).

The irrigation tails can increase the amount of water in the streams depending on several factors (type of irrigation, soils imperviousness).

In both cases, as indicated before, chemicals and organisms coming from the irrigated fields can enter water bodies. It has been known to happen in pollution of diffuse or non-point origin. This kind of water can carry, apart from salts, chemicals applied to cultivated lands, mainly pesticides and fertilizer (chemicals or manure).

Special mention must be made when water is used for golf course irrigation. This is a special application which requires well defined characteristics of water and demands large amounts of it.

Groundwater recharge

There are two types of recharge, direct or indirect:

Direct recharge is considered when water enters the aquifer through wells. For obvious reasons, the quality of such waters must be excellent. They cannot contain suspended solids because they could clog the recharge well.

Indirect recharge is achieved through surface application, using croplands or dedicated lands. In the second case, the amount of water that is used is higher than for irrigation. Because of the protection that the plant-soil system is offering to the aquifer, the applied

TABLE 4 | **Categories of reclamation depending on its final use Adapted from CEDEX, 1999.**

Number of use	Kind of reclaimed wastewater use
	Residential uses:
1	Private garden irrigation, toilet flushing, home air conditioning systems, car washing
	Urban uses and facilities:
2	Irrigation of open access landscape areas (parks, golf courses, sport fields...). Street cleaning, fire-fighting, ornamental impoundments and decorative fountains
3	Greenhouse crops irrigation
4	Irrigation of food crops consumed raw. Fruit trees irrigated with sprinklers.
5	Irrigation of pasture for milking or meat animals.
6	Irrigation of crops for canning industry and crops not raw-consumed. Irrigation of fruit trees except by sprinkling.
7	Irrigation of industrial crops, nurseries, fodder, cereals and oleaginous seeds.
8	Irrigation of forested areas, landscape areas and restricted access areas. Forestry
9	Industrial cooling, except for the food industry.
10	Impoundments, water bodies and streams for recreational use in which the public's contact with the water is permitted (except bathing).
11	Impoundments, water bodies, and streams for recreational use in which the public's contact with the water is not permitted.
12	Aquiculture (Plant or animal biomass)
13	Aquifer recharge by localised percolation through the soil
14	Aquifer recharge by direct injection

water can have a quality that is not as good as in the case of direct recharge. The soil-plant systems can degrade several contaminants and incorporate nutrients and elements.

There is a good description in Pyne (1995) about groundwater recharge possibilities, not only with reclaimed wastewater but also with other types of water. The purposes of groundwater recharge are mainly: a) increase of groundwater quantity, b) augmentation of storage in the aquifer, c) improvement of groundwater quality, d) fight against seawater intrusion, e) fight against subsidence. All of them can be attained using groundwater. Nevertheless it is necessary to compare existing groundwater and recharge water quality for a complete evaluation of the facility. Fight against intrusion can only be attained by recharge. A good description of recharge with reclaimed wastewater can be found in National Research Council-NRC (1994).

Stream augmentation and water bodies recharge

Because the extractions of water from streams are very important in many basins, there is an increasing pressure to maintain the water streams' associated ecosystems. This can be achieved using non-claimed water resources, such as reclaimed wastewater. Especially in coastal areas, wetlands and similar natural systems suffer serious pressures and competition for water resources devoted to its continuity over time. Reclaimed water can be of help in these cases.

There are additional advantages associated to both groundwater recharge and stream augmentation. The main one is that natural ecosystems will increase water quality through the action of the natural components (soils, vegetation, etc.).

The impact of reclaimed wastewater on the coastal environment

Considering the indicated possible uses of reclaimed wastewater in or near the coastline (see Table 4), water enters the natural cycle through a point application (e.g. recharge wells) or a diffuse application (e.g. agriculture).

Point applications are also to be considered in disposal systems (e.g. into a stream), while diffuse applications are typical for agricultural uses, groundwater recharge using surface application, and irrigation uses other than agricultural.

The impact of reclaimed wastewater in the environment will be in relation with the quality of this water. The quality must be in accordance with current standards. We take for comparison purposes the draft issued by

TABLE 5 **Possible uses of reclaimed wastewater in or near coastal areas.**

Use	Quality	Main Impacts	Observations
Agriculture	a) Intestinal nematode eggs: < 1 egg/L b) *E. coli*: From no limit to 200 cfu/100 mL c) Suspended solids: From 35 to 20 mg/L d) Turbidity: From No limit to < 5 NTU e) For greenhouse irrigation: o cfu/100 mL of *Legionella penumophila* f) For pasture irrigation: < 1 egg/L of *Taenia saginata and solium*	+ Reduces water extraction from natural water sources. Safe resource (availability) + Reduces wastewater disposal + Reduces risks associated to disposal - Possible contamination of foodstuffs (vegetables irrigated) - Increases salts and nitrate contents in groundwater - Risks to workers	Is the classical use for reclaimed wastewater Usually regulated by law (still not wholly in Spain) CEDEX uses nº 3, 4, 5, 6, 7 and 8.
Groundwater recharge 1) indirect recharge 2) direct recharge	a) Intestinal nematode eggs: < 1 egg/L for 1 and < 1 egg/10 L for 2 b) *E. coli*: < 1000 cfu/100 mL for 1; 0 cfu/100 mL for 2 c) Suspended solids: < 35 mg/L for 1 and < 10 for 2 d) Turbidity: From no limit (1) to < 2 NTU (2) e) Total nitrogen. From < 50 mg/L for 1 to < 15 mg/L for 2.	+ Increases the amount of water available + Reduces or limit seawater intrusion + Offers additional treatment for groundwater + Storage is obtained at a reduced cost and without compromising land surface - Can contaminate microbiologically groundwater - Increases salts and nitrate contents in groundwater	Usually, a minimum residence time (several months) is established in standards for this type of reuse CEDEX uses nº 13 and 14.
Other irrigation uses	a) Intestinal nematode eggs: from < 1 egg/L to < 1 egg/10 L b) *E. coli*: from 200 cfu/100 mL to 0 cfu/100 mL c) Suspended solids: from < 20 to < 10 mg/L d) Turbidity: From < 5 to < 2 NTU	+ Reduces water extraction from natural water sources - Risks to workers and applicants	CEDEX uses nº 1 and 2 Can be used for private purposes (irrigation of private gardens) Can be used in town (e.g. street cleaning)
Aquaculture	a) Intestinal nematode eggs: < 1 egg/L b) *E. coli*: < 1000 cfu/100 mL c) Suspended solids: < 35 mg/L d) Turbidity: no limit Use for shellfish culture prohib ited	+ For plant biomass, huge increases of yield can be obtained - For animal biomass: contamination with pathogens is possible	CEDEX use nº 12 For plant and animal biomass production
Streamflow augmentation	The only limit is for Suspended solids: < 35 mg/L No odour is allowed	+ Improvement of water related systems (wetlands, marshes…) + Improvement of landscaping values (intangibles) - Sometimes the quality could not allow fish life	CEDEX uses nº 10 and 11

CEDEX (Centro de Estudios y Experimentación de Obras Públicas) in 1999, which has been applied for local reuse cases. This draft establishes 14 categories (see Table 4) for reuse, although it can be seen that there are only 5 different types of wastewater quality. In Table 5 there are indications of the quality required for such recharge uses and the possible impacts generated.

Amounts of water

Apart from the quality of water, it is needed to know what amounts of water can be available for reclamation and reuse. This is extremely difficult to establish without controlling the amount of wastewater generated which reaches the wastewater treatment plant. In terms of quality, the limitation, especially for agriculture, is the salt contents.

Obviously, reference must be made to the water delivered to industry and urban areas. The figures range from 4 L/day in non-developed countries, to more than 1 m^3/day in specific sites in the U.S.A. A good study on water availability in Europe can be found in Angelakis (2002) and a demand study in Dziegielewski et al. (1996).

The figures are established at country level, but they do not necessarily reflect the demands and uses in a specific town. A classical average figure for Europe is 150 L/person-day for reclamation purposes.

Calculations must also be made to determine if with such a water quantity, the implementation of a reclamation facility is worth from the economic point of view. Planning procedures must also be undertaken. The feasibility must also depend on water demand and aridity of the specific area where reclamation is to be performed.

DISCUSSION AND CONCLUDING REMARKS

Because of the multiple aspects in relation with water in the coastal areas, several needs appear:

a) An integrated management of all waters in the coastal systems, including both freshwater and seawater.

b) The consideration of brackish water, non-seawater, as a potential available resource, considering that desalination technologies are being improved.

c) The consideration of non-conventional water resources into the global anthropic water management.

Several constraints are to be considered**:**

a) A strong relationship of coastal waters with human health.

b) River water must reach the sea, because of ecological (beaches, seawater productivity) considerations.

It is recommended to undertake comprehensive investigations on groundwater recharge, because it could increase the stock of available water.

Reclaimed wastewater is a resource which must be integrated within the management of water in coastal areas, especially in the arid and semiarid regions.

The interface sea-land can play a key role in the management of water. The main points of interest are seawater intrusion and the improvement of water-related systems in the shoreline (e.g. wetlands, coastal lagoons).

The interfaces seawater/freshwater are to be fully studied with respect to water flows into the sea.

Reclaimed water resources are available in the coastline, often in big quantity, and it is a necessity to implement techniques to take advantage of such resource.

Because continental water flows into the sea contribute to seawater trophic webs, careful studies must be undertaken in order to ensure viability of marine ecosystems when modifying the existing conditions of these water flows.

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