Sveriges lantbruksuniversitet
Swedish University of Agricultural Sciences

Department of Energy and Technology

Swedish Environmental Research Institute

Reclaimed Wastewater Use Alternatives and Quality Standards

From Global to Country Perspective: Spain versus Abu Dhabi Emirate

Sahar Dalahmeh

Christian Baresel

Department of Energy and Technology
Swedish University of Agricultural Sciences
IVL Swedish Environmental Research Institute

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SLU, Sveriges Lantbruksuniversitet
SUAS, Swedish University of Agricultural Sciences
Institutionen för energi och teknik
Department of Energy and Technology
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Contact
Sahar Dalahmeh, Sahar.Dalahmeh@slu.se, SLU, Box 7032, SE 75 007 Uppsala
Christian Baresel, christian.baresel@ivl.se, IVL Swedish Environmental Research Institute
Box 210 60 SE100 31 Stockholm
www.slu.se/

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Preface

The report *Reclaimed Wastewater Use Alternatives and Quality Standards – From global to country perspective: Spain versus Abu Dhabi Emirate* comprises one activity within the co-financed VINNOVA-project entitled *Tomorrows Sewage Treatment Plants – An Utility Production Facility* (Morgondagens kommunala vattenrening – en produktionsanläggning för nyttigheter. It is an open accessible report and can be downloaded at http://pub.epsilon.slu.se or http://www.ivl.se/publikationer. Parts of the report can be reproduced/used, but a clear reference to the source must be provided.

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Summary

Reclaimed wastewater use is crucial for increasing water availability, improving water resources management, minimising environmental pollution and permitting sustainable nutrient recycling. However, wastewater also contains microbiological and chemical pollutants posing risks to human health and the environment, and these risks have to be handled. Successful use of reclaimed wastewater requires stringent standards for its treatment, disposal and distribution. This report summarises global and country-specific wastewater quality standards for different reclaimed wastewater use schemes, discusses specific standards and describes reclaimed wastewater use applications in two selected countries, Spain and Abu Dhabi Emirate.

The World Health Organization (WHO) Guidelines for the Safe Use of Wastewater for Agriculture focus on the protection of public health. The European Commission does not directly regulate wastewater use, but discharge of treated wastewater into water bodies is regulated by Council Directive 91/271/EEC, which requires treated wastewater to have a maximum of 25 mg BOD_5/L, 125 mg COD/L and 35-60 mg total solids (TS)/L. In sensitive areas, sewage treatment plant effluent must comply with a maximum of 2 mg total phosphorus/L and 15 mg total nitrogen/L. EU Council Directive 2008/105/EC also sets environmental quality standards for priority substances, i.e. pesticides, polycyclic aromatic hydrocarbons, phenolic compounds and volatile organic compounds. In Spain, the EU directives and Royal Decree 1620/2007 regulate use of reclaimed wastewater. The Royal Decree sets quality criteria for microbial parameters, solids and turbidity for different applications. The Regulation and Standards Bureau (RSB) of Abu Dhabi Emirate sets the quality criteria for water discharging to marine and land environments and used for irrigation. These include limits for organic matter, solids, nutrient, pathogen indicators and helminths.

In Spain, agriculture is the largest sector for reclaimed wastewater use, consuming approx. 350 Mm^3/year. Landscape irrigation and maintenance of natural hydrological regimes are the second largest users, consuming approx. 50-60 Mm^3/year of wastewater each. In contrast, only <0.5% of the water used in industry is reclaimed wastewater. In Abu Dhabi Emirate, reclaimed wastewater is not used in crop cultivation, but most of the wastewater produced is used for irrigation of public parks and roadsides (287 Mm^3/year) and in forestry (130 Mm^3/year). District cooling in residential areas is another application for wastewater use in Abu Dhabi Emirate.

The technologies used to facilitate wastewater treatment vary. The Barcelona metropolitan wastewater treatment plant (Spain), which supplies reclaimed wastewater for use, conducts biological treatment with activated sludge, tertiary treatment with coagulation-flocculation, filtration, UV disinfection, post-disinfection and oxygen saturation. The effluent wastewater complies with the Royal Decree and EU directives. In contrast, five treatment plants in the Navarra

region of Spain use secondary treatment with trickling filters or activated sludge, two having lagoons for tertiary treatment. The hygiene quality of effluent from these plants does not comply with the Royal Decree and several fail to remove persistent organic compounds and pharmaceutical residues effectively. In Abu Dhabi Emirate, the largest sewage treatment plant, Mafraq, carries out conventional activated sludge treatment, followed by sand filtration and chlorination. Its effluent complies with RSB standards, but occurrence of pharmaceutical residues in effluent wastewater has been documented in Abu Dhabi.

Besides standards and regulations and appropriate treatment, other aspects which need consideration in planning reclaimed wastewater use for various applications include: cultural and socio-economic aspects, willingness of users to accept and pay for treated wastewater, online and real-time water quality monitoring, and reduced energy use and waste generation

Sammanfattning

Återanvändning av renat avloppsvatten underlättar vattenresursförvaltningen då den ökar tillgången till vatten, minimerar föroreningen av naturliga vattenmiljöer och dessutom kan bidra till en förbättrad hushållning med näringsämnen och energi. För att fördelarna med återanvändning av vatten skall väga över behöver dock riskerna hanteras. Riskerna är främst kopplade till mikrobiologiska och kemiska föroreningar som finns i avloppsvatten och som utgör en fara för både människor och miljön. En lyckad återanvändning av avloppsvatten kräver strikta normer för såväl rening som återanvändning. Denna rapport sammanfattar globala och landsspecifika kvalitetsstandarder och kriterier för olika återanvändningsalternativ. Rapporten ger även inblick i specifika standarder och återanvändningssystem i två utvalda länder; Spanien och Abu Dhabi.

Världshälsoorganisationens (WHO) riktlinjer för säker återanvändning av renat avloppsvatten i jordbruk fokuserar på att skydda folkhälsan. De definierar det hälsobaserade måttet "Disability Adjusted Life Years (DALY)" som kvalitetskriterium för återanvändning. Europeiska Kommissionen reglerar inte direkt återanvändning av renat avloppsvatten. Istället regleras utsläpp av renat avloppsvatten till vattendrag i direktivet 91/271/EEG. Direktivet kräver till exempel att renat avloppsvatten som mest får innehålla 25 mg BOD5/L, 125 mg COD/L och 35 till 60 mg TS/L. I områden som är känsliga för övergödning ställs dessutom krav på maximalt 2 mg totalfosfor (TP)/L och 15 mg totalkväve (TN)/L. Rådets direktiv 2008/105/EG innehåller dessutom miljökvalitetsnormer för prioriterade ämnen, dvs. bekämpningsmedel, polycykliska aromatiska kolväten (PAH), fenolföreningar och flyktiga organiska föreningar. I Spanien är det EU-direktiven och den kungliga förordningen 1620/2007 som används för att reglera återanvändning av avloppsvatten. Förordningen 1620/2007 fastställer kvalitetskriterier för mikrobiella parametrar, fasta partiklar och grumlighet för olika återanvändningsalternativ. Regulation and Standards Bureau (RSB) i emiratet Abu Dhabi ställer krav på kvaliteten på renat avloppsvatten innan det får släppas ut till havs-och landmiljöer, inklusive bevattning. Kriterierna omfattar gränsvärden för organiska ämnen, partiklar, näringsämnen, patogener och parasitära maskar.

I Spanien är jordbruket den samhällssektor som återanvänder mest renat avloppsvatten, ca 350 Mm^3/år. Två andra stora användningsområden återanvänt avloppsvatten är landskapsbevattning och återföring av vatten till naturliga vattenmiljöer för bibehållande och återställande, med cirka 50-60 Mm^3/år vardera. Återanvändning inom industrin är blygsam och mindre än 0,5 % av den totala industriella vattenanvändningen utgörs av renat avloppsvatten.

I Abu Dhabi används inget renat avloppsvatten för odling av livsmedelsgrödor men däremot för bevattning av offentliga parker och vägkanter (287 Mm^3/år), och skogsbruk (130 Mm^3/år). En annan sektor som använder renat avloppsvatten i Abu Dhabi är fjärrkyla i stora bostadsområden.

Teknikerna för att rena avloppsvatten som skall återanvändas varierar. I Spanien renar Barcelonas reningsverk avloppsvattnet som skall återanvändas med sekundär biologisk behandling (aktiv slam) samt tertiär behandling med koagulering och flockning, filtrering, UV- desinfektion, post-desinfektion och därefter syremättning. Fem reningsverk i regionen Navarra har däremot bara sekundär behandling med biobäddar eller aktivt slam som i två av verken kompletterats med laguner för tertiär rening. Det renade avloppsvattnet i Barcelona uppfyller kraven i förordning 1620/2007 och EU-direktivet, men inte det renade vattnet från reningsverken i Navarra. Dessutom misslyckas flera reningsverk med att effektivt ta bort långlivade organiska ämnen och läkemedelsrester. Det största avloppsvattenreningsverket i Abu Dhabi, "Mafraq", består av konventionell aktivslambehandling följt av sandfilter, och klorering. Dess renade vatten uppfyller standarderna för återanvändning enligt Regulation and Standards Bureau (RSB), trots att även detta renade avloppsvatten innehåller läkemedelsrester.

Förutom de standarder och kriterier som finns är det flera andra aspekter som behöver beaktas i planeringen för återanvändning av avloppsvatten för olika tillämpningar. Dessa innefattar bland annat kulturella och socioekonomiska aspekter och kundens vilja att använda och betala för renat avloppsvatten. Den snabba utvecklingen av bättre reningsprocesser och möjligheten att i realtid säkerställa vattenkvaliteten kan kanske bidra till en ökad acceptans för återanvändning av renat avloppsvatten.

1 Introduction

Historically, the relationship between disease and wastewater pollution following heavy pollution of rivers by wastewater was the driver for introducing systems for collection and treatment of wastewater (Wiesmann *et al.*, 2006). In the world today, there is a paradigm shift towards looking at wastewater more as a valuable resource rather than a waste, although the relationship between wastewater and pollution is still problematic.

Wastewater is available all year around. Thus, it is reliable source that can be used in regions with water scarcity or prolonged periods of drought. Rapid population growth, intensive agricultural activities, the need for sustainable water sources to meet the environmental restrictions on construction of storage reservoirs for potable water and the long distances between cities and water sources are other factors promoting more reclaimed wastewater use (Iglesias and Ortegal, 2008). Once the reclaimed wastewater is used, other benefits can be seen such as: increased water availability, improved water resources management by wise allocation of different types of water resources, decreased pollution input into water courses and re-use of the nutrients in the reclaimed wastewater, decreasing the need for fertiliser (Iglesias and Ortegal, 2008).

Reclaimed wastewater use brings a number of challenges and complex questions regarding which contaminants must be removed and to what extent must be answered specifically, for each case, considering local conditions, needs, scientific knowledge, regulations and requirements (Tchobanoglous *et al*., 2002). Thus, reclaimed wastewater use requires planned strategies that incorporate multiple measures to minimise public health and environmental risks. This means that combinations of source control, treatment processes, flow schemes and other engineering controls should be the basis for reclaimed wastewater use (Asano and Levine, 1996).

This report discusses relevant reclaimed wastewater use schemes, possible users (sectors) and associated quality standards and regulations for different reuse options using the example of two selected countries (Spain and Abu Dhabi Emirate in United Arab Emirates (UAE)). The overriding aim of the work was to provide information to help in the selection of treatment processes/systems or technologies which render reclaimed wastewater eligible for certain reuse purposes. Spain was selected due to the fact it is an EU country with high water demand for agriculture and follows common European regulations. Abu Dhabi Emirate was selected because of its extremely low freshwater availability, its rapid growth and its high importance as regional and global economic centre.

The World Health Organization (WHO) has developed general guidelines and standards for wastewater use that are intended as a reference or guide to regulating agencies in various countries in developing their own reclaimed wastewater use regulations and monitoring programmes (WHO, 2006). The European legislation is governed by Council Directive 91/271/EEC (1991) concerning urban wastewater treatment. In Spain, the criteria for reclaimed wastewater use were first based on the WHO criteria, until the extended and stronger Royal Decree 1620/2007 came into force.

The stringent water quality standards imposed with the introduction of the Royal Decree 1620/2007 in Spain and the creation of the Regulation and Standards Bureau (RSB) in Abu Dhabi have bought new scrutiny to the existing water treatment and distribution systems. From a technological development perspective, the new water quality standards have opened up the market for new wastewater treatment technologies to upgrade existing wastewater treatment plants in these countries.

Spain, with a population of 47.27 million people (World Population Statistics, 2013), has an economy that includes a number of service sectors related to tourism (70% of gross domestic product (GDP)), industry (25% GDP) and agriculture (5% GDP). Use of reclaimed wastewater accounts for 368 Mm^3/year (2005-2007; Iglesias *et al*., 2010). The remarkable growth in agricultural activities and the competition between agriculture, tourism and municipal water demand in Spain are the major drivers for reclaimed wastewater use (Jiménez and Asano, 2008). There have been major investments in sewerage and wastewater treatment infrastructure, mainly during the last decade after implementation of 91/271/EEC and enforcement of Royal Decree 509/1996 (Iglesias and Ortegal, 2008), followed by Royal Decree 1620/2007.

United Arab Emirates (6.05 million inhabitants) is a leading economic centre regionally and globally. In 2009, UAE had a GDP of 245.5 billion USD, composed of agriculture (1.1%), industry (48.6%) and services (50.2%) (ICT, 2001). Abu Dhabi Emirate is the largest of its seven emirates. In UAE, freshwater availability per capita and year is <200 m^3 (Nimat, 2008), but water consumption is >550 L per capita and day (ACWUA, 2010), the third highest water consumption per capita in the world. About 70% of the water is obtained from non-conventional water resources, mainly desalinated water and treated wastewater (Rizk and Alsharhan, 2003). The amount of treated wastewater in UAE was 560 Mm^3/year in 2009 (Al-Mulla, 2011), of which 487 Mm^3/year were reused almost entirely by redistribution to green areas (Sato *et al.*, 2013).

2 Reclaimed Wastewater Use Alternatives

There are a number of reclaimed wastewater use alternatives. The agricultural, industrial, urban and environmental sectors represent the most common uses of reclaimed wastewater. A characteristic common to all reuse alternatives is that they use reclaimed wastewater exclusively for non-potable applications. Except in extreme applications, such as spacecraft, reclaimed wastewater may not be used as drinking water. However, several indirect potable reuse applications are possible, among which water discharge to natural streams, lakes or aquifers may be the most promising, representing a combination of urban and environmental use. In fact, treated wastewater is already used today for other purposes through unplanned routes. This *de facto* wastewater use occurs e.g. when the drinking water supply of a region is based on natural waters that contain upstream sewage treatment effluent. For example, the water supply for the Stockholm region in Sweden is based on water from wastewater treatment works close to the Norrström basin outlet in Lake Mälaren. Around 2% of this water is sewage treatment effluent from upstream communities, which provides 10% of the nitrogen in the water (Baresel and Destouni, 2005).

2.1 Agricultural Use

Irrigation with reclaimed wastewater in agriculture is one of the most common uses of (treated and untreated) wastewater. The method combines recycling of water and nutrients (mainly nitrogen and phosphorus). Irrigation is particularly important in water-scarce regions such as the Middle East and the Mediterranean. This application is divided into restricted and non-restricted irrigation. In restricted irrigation, lower water quality is allowed for certain agricultural crops such as fodder crops, fibre crops, seed crops, pasture, commercial nurseries, turf grass and commercial aquaculture. In non-restricted irrigation, high-quality treated wastewater is used for food crops, including those eaten raw (Exall, 2004). According to EAAD (2009), the fertiliser value of the natural nutrients in Abu Dhabi wastewater is worth about 3.0 USD/m^3, which could save farmers about 130.0 USD/ha/year in fertiliser costs if treated wastewater were used for irrigation. The hygiene quality of the wastewater is the main aspect to consider when wastewater is used in agriculture. This is to prevent transmission of wastewater pathogens to humans.

2.2 Industrial Use

Reclaimed wastewater recycling in industry is especially important in industries with high water usage, e.g. the metal manufacturing, paper and plastic industries. In metallurgy and metal manufacturing, most of the water is used for cooling, but high water purity is needed to avoid rusting, biological fouling and scale formation (deposition of phosphorus, calcium and magnesium) (Rebhun and Gideon, 1988), which involves advanced treatment of wastewater for the removal of ammonia and phosphates, reduction in alkalinity, hardness and calcium, and reduction in suspended and dissolved solids (Rebhun and Gideon, 1988).

2.3 Urban Use

Urban uses of reclaimed wastewater include toilet flushing, garden irrigation, landscape irrigation (parks and golf courses), street cleaning, fire hydrants and industrial washing of vehicles. In addition, water use in tourism can be added to the list of urban uses of wastewater. Recharge of groundwater or other natural water systems can be also included in this category if the objective is to facilitate increased water withdrawal for potable water use.

2.4 Environmental Use

Environmental uses of reclaimed wastewater include groundwater injection, irrigation of woodland and maintenance of wetlands, and supplementing environmental and ecological flows such as stream flows. In this category, recreational impoundments such as ponds and lakes can also be included.

3 Standards for Reclaimed Wastewater Use

Disease-causing microorganisms, i.e. pathogens, in wastewater pose a direct health threat to humans upon direct or indirect exposure to wastewater. Thus, protection of public health is usually the focus in any discussion regarding wastewater recycling. Consequently, standards and regulations, e.g. WHO guidelines for wastewater use, were established many decades ago, and updated in 2006, with main goal of public health protection. Protection of water sources by minimising eutrophication is a secondary goal for setting standards and regulations on wastewater disposal and use. This has resulted in stringent standards for the removal of phosphorus and nitrogen during wastewater treatment, as well as strict standards for wastewater disposal, e.g. the EU directive on the disposal of wastewater. Recently, emerging pollutants such as pharmaceuticals and other micropollutants have begun to receive attention due to their persistent nature and effects on the environment. The following section presents selected guidelines and standards for reuse and disposal of wastewater.

3.1 World Health Organization Guidelines for the Safe Use of Wastewater

Maximising protection of public health and beneficial use of important resources are the primary aims of WHO guidelines (WHO, 2006). This can be done either by removing wastewater pathogens during wastewater treatment processes, or by preventing the exposure of humans to pathogens using barriers (WHO, 2006). In the first set of WHO wastewater use guidelines (WHO 1973), there was a guideline value of 100 coliforms/100 mL for unrestricted irrigation, together with recommendations on secondary treatment followed by chlorination and/or filtration. The latest guidelines (WHO 2006) focus on health risk assessment and management approaches (including standards and regulations). Instead of setting an allowable concentration of a certain pathogen in the wastewater used in agriculture, the new guidelines set a health-based target Disability Adjusted Life

Years (DALY) value of 10^{-6}. This health-based target defines a level of health protection that is relevant for each hazard. For example, if untreated wastewater is to be used for irrigation of lettuce, this requires single or multiple health protection measures to achieve a 6 log reduction in pathogens in the wastewater and 1 helminth eggs/L wastewater (WHO, 2006). The health protection measures can comprise treatment of the wastewater, as well as irrigation method, crop selection etc. (WHO, 2006).

In many countries where national guidelines are absent, the WHO guidelines serve as the basis for the development of national standards. As such, the limits recommended are not mandatory, but should be used together with national or regional standards and considering local or national environmental, social, economic and cultural conditions, in the development of risk management strategies.

The WHO guidelines on wastewater use are continuously discussed and criticised as not being sufficient for human health protection. However, the guidelines have influenced a number of national standards such as the Spanish guidelines for wastewater use.

3.2 EU Directives

So far, no specific regulation on reclaimed wastewater use exists at European level. The only references to reclaimed wastewater use are Article 12 of the European Wastewater Directive (91/271/EEC) (EC, 1991), the Water Framework Directive 2000/60/EC (EC, 2000) and, specifically, EU Directive 2008/105/EC on Environmental Quality Standards (EC, 2008).

3.2.1 Council Directive 91/271/EEC Concerning Urban Wastewater Treatment

According to Directive 91/271/EEC - Article 12, treated wastewater must be reused whenever appropriate and disposal routes must minimise any adverse effects on the environment. Therefore, before disposal of treated wastewater into water bodies, the treated wastewater from municipal wastewater treatment plants must meet the water quality parameters shown in Table 1 (EC, 1991). It should be pointed out that removal of nitrogen and phosphorus is necessary in sensitive areas, i.e. areas subject to eutrophication, surface waters intended for the abstraction of drinking water, or areas where further treatment is necessary to fulfil Council Directives.

Table 1. Requirements for discharge from urban wastewater treatment plants (Directive 91/271/EEC).

Parameter	Concentration (mg/ L)	Reduction (%)
Biochemical Oxygen Demand (BOD5)	25	70-90
Chemical Oxygen Demand (COD)	125	75
Total Suspended Solids (TSS)	35-60*	70-90**
Total nitrogen (Tot-N) ***	2	80
Total phosphorus (Tot-P) ***	15	70-80

*Depending on population. 35 mg/L for more than 10 000 person equivalents (PE) and 60 mg/L for 2000-1000 PE.
** Depending on population. 90 mg/L for more than 10 000 PE and 70 mg/L for 2000-1000 PE.
*** These parameters are required in sensitive areas.

As can be seen from Table 1, Directive 91/271/EEC focuses on conventional wastewater treatment quality parameters with the aim of avoiding eutrophication and oxygen depletion. Quality requirements for pathogenic contamination and microorganic pollution with pharmaceuticals are not set/determined in this directive. Instead, industrial wastewater entering collection systems and urban wastewater treatment plants must be subjected to pre-treatment in order to:

- protect the health of staff working in collection systems and treatment plants
- ensure that collection systems, wastewater treatment plants and associated equipment are not damaged
- ensure that operation of the wastewater treatment plant and treatment of sludge are not impeded
- ensure that discharges from the treatment plants do not adversely affect the environment, or prevent receiving water from complying with other Community Directives
- ensure that sludge can be disposed of safety in an environmentally acceptable manner (EC, 1991).

3.2.2 Council Directive 2008/105/EC: Environmental Quality Standards for Priority Substances and Certain Other Pollutants

The levels of priority pollutants, which include pesticides, polycyclic aromatic hydrocarbons (PAH), phenolic compounds and volatile organic compounds, is currently regulated through the European Water Framework Directives (EC, 2000; EC, 2008). The environmental quality standards (EQS) are presented in Table 2.

Table 2. Environmental Quality Standards (EQS) for priority pollutants. Table adapted as is from the source (EC, 2008). All values µg/L.

Name of substance	CAS number (1)	AA-EQS (2) Inland surface waters (3)	AA-EQS (2) Other surface waters	MAC-EQS (4) Inland surface waters (3)	MAC-EQS (4) Other surface waters
Alachlor	15972-60-8	0.3	0.3	0.7	0.7
Anthracene	120-12-7	0.1	0.1	0.4	0.4
Atrazine	1912-24-9	0.6	0.6	2.0	2.0
Benzene	71-43-2	10	8	50	50
Brominated diphenylether (5)	32534-81-9	0.0005	0.0002	Not applicable	Not applicable
Cadmium and its compounds (depending on water hardness classes) (6)	7440-43-9	≤ 0.08 (Class 1) 0.08 (Class 2) 0.09 (Class 3) 0.15 (Class 4) 0.25 (Class 5)	0.2	≤ 0.45 (Class 1) 0.45 (Class 2) 0.6 (Class 3) 0.9 (Class 4) 1.5 (Class 5)	≤ 0.45 (Class 1) 0.45 (Class 2) 0.6 (Class 3) 0.9 (Class 4) 1.5 (Class 5)
Carbon-tetrachloride (7)	56-23-5	12	12	Not applicable	Not applicable
C10-13 Chloroalkanes	85535-84-8	0.4	0.4	1.4	1.4
Chlorfenvinphos	470-90-6	0.1	0.1	0.3	0.3
Chlorpyrifos (Chlorpyrifos-ethyl)	2921-88-2	0.03	0.03	0.1	0.1
Cyclodiene pesticides: Aldrin (7) Dieldrin (7) Endrin (7) Isodrin (7)	 309-00-2 60-57-1 72-20-8 465-73-6	Σ = 0.01	Σ = 0.005	Not applicable	Not applicable
DDT total (7) (8)	not applicable	0.025	0.025	Not applicable	Not applicable
para-para-DDT (7)	50-29-3	0.01	0.01	Not applicable	Not applicable
1,2-Dichloroethane	107-06-2	10	10	Not applicable	Not applicable
Dichloromethane	75-09-2	20	20	Not applicable	Not applicable
Di(2-ethylhexyl)-phthalate (DEHP)	117-81-7	1.3	1.3	Not applicable	Not applicable
Diuron	330-54-1	0.2	0.2	1.8	1.8
Endosulfan	115-29-7	0.005	0.0005	0.01	0.004
Fluoranthene	206-44-0	0.1	0.1	1	1
Hexachloro-benzene	118-74-1	0.01 (9)	0.01 (9)	0.05	0.05
Hexachloro-butadiene	87-68-3	0.1 (9)	0.1 (9)	0.6	0.6
Hexachloro-cyclohexane	608-73-1	0.02	0.002	0.04	0.02
Isoproturon	34123-59-6	0.3	0.3	1.0	1.0
Lead and its compounds	7439-92-1	7.2	7.2	Not applicable	Not applicable
Mercury and its compounds	7439-97-6	0.05 (9)	0.05 (9)	0.07	0.07
Naphthalene	91-20-3	2.4	1.2	Not applicable	Not applicable
Nickel and its compounds	7440-02-0	20	20	Not applicable	Not applicable
Nonylphenol (4-Nonylphenol)	104-40-5	0.3	0.3	2.0	2.0
Octylphenol ((4-(1,1′,3,3′-tetramethylbutyl)- phenol))	140-66-9	0.1	0.01	Not applicable	Not applicable
Pentachloro-benzene	608-93-5	0.007	0.0007	Not applicable	Not applicable
Pentachloro-phenol	87-86-5	0.4	0.4	1	1
Polyaromatic hydrocarbons (PAH) (10)	not applicable	not applicable	not applicable	Not applicable	Not applicable
Benzo(a)pyrene	50-32-8	0.05	0.05	0.1	0.1
Benzo(b)fluor-anthene	205-99-2	Σ = 0.03	Σ = 0.03	Not applicable	Not applicable
Benzo(k)fluor-anthene	207-08-9				
Benzo(g,h,i)-perylene	191-24-2	Σ = 0.002	Σ = 0.002	Not applicable	Not applicable
Indeno(1,2,3-cd)-pyrene	193-39-5				
Simazine	122-34-9	1	1	4	4
Tetrachloro-ethylene (7)	127-18-4	10	10	Not applicable	Not applicable
Trichloro-ethylene (7)	79-01-6	10	10	Not applicable	Not applicable
Tributyltin compounds (Tributhyltin-cation)	36643-28-4	0.0002	0.0002	0.0015	0.0015
Trichloro-benzenes	12002-48-1	0.4	0.4	Not applicable	Not applicable
Trichloro-methane	67-66-3	2.5	2.5	Not applicable	Not applicable
Trifluralin	1582-09-8	0.03	0.03	Not applicable	Not applicable

(1) AA: Annual Average.
(2) CAS: Chemical Abstracts Service.
(3) This parameter is the EQS expressed as an annual average value (AA-EQS). Unless otherwise specified, it applies to the total concentration of all isomers.
(4) Inland surface waters encompass rivers and lakes and related artificial or heavily modified water bodies.
(5) This parameter is the EQS expressed as a maximum allowable concentration (MAC-EQS). Where the MAC-EQS are marked as 'not applicable', the AA-EQS values are considered protective against short-term pollution peaks in continuous discharges since they are significantly lower than the values derived on the basis of acute toxicity.
(6) For the group of priority substances covered by brominated diphenylethers (No. 5) listed in Decision No 2455/2001/EC, an EQS is established only for congener numbers 28, 47, 99, 100, 153 and 154.
(7) For cadmium and its compounds (No. 6), the EQS values vary depending on the hardness of the water as specified in five class categories (Class 1: < 40 mg $CaCO_3$/L, Class 2: 40 to < 50 mg $CaCO_3$/L, Class 3: 50 to < 100 mg $CaCO_3$/L, Class 4: 100 to < 200 mg $CaCO_3$/L and Class 5: ≥ 200 mg $CaCO_3$/L).
(8) This substance is not a priority substance but one of the other pollutants for which the EQS are identical to those laid down in the legislation that applied prior to 13 January 2009.
(9) DDT total comprises the sum of the isomers 1,1,1-trichloro-2,2 bis (p-chlorophenyl) ethane (CAS number 50-29-3; EU number 200-024-3); 1,1,1-trichloro-2 (o-chlorophenyl)-2-(p-chlorophenyl) ethane (CAS number 789-02-6; EU number 212-332-5); 1,1-dichloro-2,2 bis (p-chlorophenyl) ethylene (CAS number 72-55-9; EU number 200-784-6); and 1,1-dichloro-2,2 bis (p-chlorophenyl) ethane (CAS number 72-54-8; EU number 200-783-0).
(10) If Member States do not apply EQS for biota, they must introduce stricter EQS for water in order to achieve the same level of protection as the EQS for biota set out in Article 3(2) of the Directive. They must notify the Commission and other Member States, through the Committee referred to in Article 21 of Directive 2000/60/EC, of the reasons and basis for using this approach, the alternative EQS for water established, including the data and the methodology by which the alternative EQS were derived, and the categories of surface water to which they would apply.
(11) For the group of priority substances of polyaromatic hydrocarbons (PAH) (No 28), each individual EQS is applicable, i.e. the EQS for Benzo(a)pyrene, the EQS for the sum of Benzo(b)fluoranthene and Benzo(k)fluoranthene and the EQS for the sum of Benzo(g,h,i)perylene and Indeno(1,2,3-cd)pyrene must be met.

3.3 Spanish Guidelines for Reclaimed Wastewater Use: Royal Decree 1620/2007

Royal Decree 1620/2007 established reclaimed wastewater use quality criteria based on maximum admissible values, which take into account hygiene risks and other pollutants, depending on the uses for which the treated water is destined. Table 3 shows the reuse options and quality of wastewater needed for each reuse option (Royal Decree 1520/2007, 2007). The quality criteria in the Spanish guidelines are limited to microbial parameters, solids and turbidity. In cases where the wastewater contains hazardous substances, such as halogenated hydrocarbons, persistent organic compounds, mercury and cadmium, the reclaimed wastewater must comply with the environmental quality standards (Royal Decree 1520/2007, 2007). Because Spain is an EU country, disposal of wastewater to the environment must comply with EU Council Directive 91/271/EEC concerning urban wastewater treatment. The requirements in this directive are discussed in the following section.

Table 3. Royal Decree 1620/2007 requirements for the use of wastewater in Spain.

Reuse Option	Intestinal nematodes (eggs/10 L)	E.coli (CFU*/ 100 mL)	Suspended solids (mg/L)	Turbidity (NTU**)
Urban use				
Garden irrigation	1	0	10	2
Landscape irrigation, street cleaning, fire hydrants and car washing	1	200	20	10
Agricultural use				
Crops irrigated using irrigation methods resulting in contact between water and crops eaten raw	1	100	20	10
Crops irrigated using irrigation methods resulting in contact between water and crops not eaten raw, pasture irrigation for milk and meat production, aquaculture	1	1000	35	No limit
Tree fruits, greenhouse crops where crops are not in direct contact with water, ornamental crops, non-food industrial crops	1	10 000	35	No limit
Industrial use				
Industrial uses including cleaning and processing water, except for food industry	No limit	10 000	35	15
Process and cleaning water for food industry	1	1000	35	No limit
Cooling towers and evaporative condensers	1	Absence	5	1

*Coliform-forming units
**Nephelometric Turbidity Units

3.4 Abu Dhabi Guidelines for Wastewater Disposal and Use

The United Arab Emirates have special characteristics such as their small scale, predominantly urban setting and fast growth. Furthermore, while Abu Dhabi has a strategy for its wastewater treatment and reuse, Dubai is still struggling with one overloaded sewage treatment plant and illegal dumping (ACWUA, 2010).

According to the RSB for Abu Dhabi (RSB, 2010b), the minimum requirements for treated wastewater at the point of transfer or discharge to the marine environment or to land should comply with quality criteria summarised in Table 4. For the reuse of wastewater in irrigation, additional guidelines apply. These additional guidelines (Table 4 mainly focus on trace elements. In addition, a licence for the reuse of wastewater for irrigation needs to be obtained from the RSB (RSB, 2010b).

Table 4. Abu Dhabi/UAE guidelines for the reuse of wastewater for different reuse options (RSB, 2010b). Units are mg/ L unless otherwise indicated.

	Reuse option			
Parameter	General reuse	Restricted reuse	Disposal into sea	Land percolation
Faecal coliforms (CFU/100 mL)	100	1000	1000	100
Intestinal enterococci (CFU/100 mL)	40	200	-	40
Helminth ova (eggs/L)	<0.1	<1	0	<0.1
pH	6-8	6-8	6-8	6-8
BOD5	10	10	50	10
Total suspended solids	10	20	50	10
Ammonia nitrogen	-	-	2	-
Total phosphorus	-	-	2	-
Turbidity	5	10	75	10
Residual chlorine	0.5-1	0.5-1	1	0.5-1
Dissolved oxygen	≥1	≥1	≥3	≥1

Table 5. RSB criteria for trace elements in wastewater use in irrigation.

Parameter	Maximum allowable concentration (mg/L)
Aluminium	5.0
Arsenic	0.1
Beryllium	0.1
Cadmium	0.01
Chromium	0.1
Cobalt	0.05
Copper	0.2
Fluoride	1.0
Iron	5.0
Lead	5.0
Lithium	2.5
Manganese	0.2
Molybdenum	0.01
Nickel	0.2
Selenium	0.02
Vanadium	0.1
Zinc	2.0

In connection with wastewater, RSB has set requirements for the bio-solids content at the point of transfer from the wastewater treatment facility (RSB, 2010b). These requirements focus on the microbial quality and trace elements. Table 6 presents the criteria for bio-solids disposal in Abu Dhabi/UAE. The regulations on bio-solids mean that the wastewater treatment facility must be designed to produce bio-solids that comply with these regulations.

Table 6. RSB guidelines on disposal of bio-solids in Abu Dhabi/UAE.

	Unrestricted Use	Restricted Use
E. coli (CFU/g DM)	<1000	<100000
Salmonella (CFU/2g DM)	<1	Not applicable
Helminth ova (no./50g DM)	<1	<10
Arsenic (mg/kg)	20	75
Cadmium (mg/kg)	1	20
Chromium (mg/kg)	400	1000
Copper (mg/kg)	150	1000
Lead (mg/kg)	300	750
Mercury (mg/kg)	1	10
Nickel (mg/kg)	60	300
Selenium (mg/kg)	3	50
Zinc (mg/kg)	300	2500

No regulation regarding the maximum allowable limits of persistence organic pollutants (POP) in effluent wastewater exists for Abu Dhabi. However, RSB has set limits for the maximum concentration of POP allowed to be discharged into wastewater stream (Table 7) (RSB, 2010a).

Table 7. Maximum concentrations of persistence organic pollutants (POP) allowed to be discharged into the sewer system in Abu Dhabi (RSB, 2010a).

Class	Concentration (mg/L)
Phenolic compounds	0.5
Polycyclic aromatic compounds (PAH)	0.05
Organophosphorus pesticides	0.01
Organochlorine pesticides	0.01

4 County-specific Examples of Reclaimed Wastewater Use

4.1 Spain

In Spain, water use for agriculture and animal rearing is 16.69 x 10^3 Mm^3/year (Cazcarro *et al.*, 2014). Reclaimed wastewater use in cultivation is about 346 Mm^3/year (Pedrero *et al.*, 2010). Future reclaimed wastewater use in Spain is expected to focus on coastal areas of the Mediterranean, the South Atlantic arc and the Balearic and Canary Islands (Iglesias *et al.*, 2010). This is due to the increasing water demand associated with development of agriculture, industry and tourism, as well as the need to secure a sustainable water resource within an acceptable distance (Iglesias *et al.*, 2010). While the conditions are promising for reuse, a challenge will arise due to the high salinity of the wastewater, rendering the water unsuitable for the crops grown in those areas (Iglesias and Ortegal, 2008). This in turn will demand careful selection of treatment system, with particular emphasis on desalination to produce usable water.

Industrial freshwater use accounts for 630 Mm^3/year (Cazcarro *et al.*, 2014), with the production and distribution of electricity and gas the largest industrial consumers of water (340 Mm^3/year), followed by the food industry (90 Mm^3/year), metallurgy and metal manufacturing (70 Mm^3/year), the paper industry (70 Mm^3/year) and rubber and plastics (60 Mm^3/year) (Cazcarro *et al.*, 2014). In contrast, industrial reclaimed wastewater use in Spain is very limited (1-3 Mm^3/year in 2004-2007) (Iglesias and Ortegal, 2008; Iglesias et al., 2010).

Urban (including recreational and golf course) reclaimed wastewater use accounts for 58 Mm^3/year (Iglesias and Ortegal, 2008); making it the second largest sector reusing treated wastewater. As for water in tourism, Cazcarro *et al.* (2014) reported that water (virtual water in food and drinks) provided by restaurants and bars and hotel activities (cleaning, washing and laundry, swimming pools) all result in high water consumption in the tourism sector in Spain (20 Mm^3/year). The high water usage in hotels implies good potential for recycling of hotel wastewater onsite for flushing toilets. In such cases, advanced treatment is required to bring wastewater to tab water standards in the case of laundry use and total disinfection in the case of flush water.

Environmental water use includes forestry (810 Mm^3 fresh water/year) (Iglesias and Ortega, 2008). Wastewater use in forestry has been practised since the 1960s (FAO, 2013). However, water consumption for wood and wood products declined from 29 Mm^3/year in 1980 to 4 Mm^3/year in 2007, which might indicate marginal importance of water use, in general, for forestry.

In addition to forestry, wastewater is used for maintaining environmental flows. For example, in Barcelona 50 Mm^3/year of treated wastewater are used for reducing the deficit in ecological flow in the Liobregat and Ter Rivers (Cazurra, 2008). Wastewater treated at tertiary level is discharged into these rivers (Köck-Schulmeyer *et al.*, 2011) in order to prevent eutrophication and pollution. According to Cazurra (2008), the criteria for wastewater intended for ecological flows are $\leq$10 mg BOD_5/L, <5 NTU for turbidity, <10 CFU/100mL of faecal coliforms, <1 nematode egg/L, >0.6 xx/L residual chlorine and ≥7.5 xx/L dissolved oxygen.

4.2 Abu Dhabi Emirate

In Abu Dhabi, the area of cultivated land is about 88 000 ha (Al-Mulla, 2011). The agricultural water use in Abu Dhabi in 2007 was 1489 Mm^3 (EAAD, 2009). According to the Abu Dhabi Environmental Agency, 1413 Mm^3 groundwater and 76 Mm^3 desalinated water are used annually for agriculture. According to Jiménez and Asano (2008), the amount of reclaimed wastewater used for irrigation is ≈170 Mm^3/year, while Al-Mulla (2011) reported that 287 Mm^3/year of reclaimed wastewater are used for irrigation in public parks and greening of road verges and roundabouts, but no reclaimed wastewater is used for agriculture.

Industry accounts for 17% of GDP in UAE (2002), with oil and petrochemicals as the base industry (EAAD, 2009). In recent years, food and technology-based industries (e.g. assembly of computers and electronic equipment) have increased (EAAD, 2009; Pacione, 2005). Industrial water use in Abu Dhabi is 46 Mm^3/year (EAAD, 2009), all of which is obtained from internal desalination plants within industrial facilities. The water used in industry is divided into three categories: process water with potable water requirement, washing water with potable to more inferior water quality and cooling water (sea water quality for internal cooling) (EAAD, 2009). Awareness and action on industrial reclaimed wastewater use in UAE have progressed during the last few years, e.g. one company has signed a major contract covering the delivery of 20 mobile wastewater treatment plants with 12 filtration units each to the Dubai region (Nanovation, 2008).

As for urban wastewater use, UAE uses 389 Mm^3/year of wastewater for urban uses, of which 287 Mm^3/year are used for irrigating parks and amenities (Al-Mulla, 2011). In addition, wastewater produced in mega-housing areas on the periphery of Abu Dhabi is treated and recycled in district cooling (McDonnell, 2013). However, it should be clarified here that the reclaimed wastewater use in district cooling is treated in local facilities operated by the housing companies. The demand for reclaimed wastewater use in urban applications is expected to increase from 187 m^3/day in 2008 to 333 m^3/day in 2015 (EAAD, 2009). United Arab Emirates has various attractions for tourists in different activities (e.g. Dubai festival). Between 1993 and 2000, the number of hotel rooms in Dubai increased by 37%, from 18 638 to 25 571, and number of hotel beds by 32%, from 31 267 to 41 226. However, no data are available on water consumption in tourism in UAE.

The environmental use of water is mainly for forest irrigation, which used 709 Mm^3 in 2007 (EAAD, 2009). 130 Mm^3/year of treated wastewater are used in forestry; the rest (579 Mm^3/year) is obtained from groundwater resources (EAAD, 2009; Al-Mulla, 2011). In the future, increased awareness about the nutrients and organic content of wastewater will hopefully result in it being considered a useful and appropriate resource for forest irrigation in arid and infertile land in countries such as UAE.

5 County-specific Wastewater Treatment Schemes

5.1 Spain

Spain established National Sewerage and Water Treatment Plan 95-2005 (NSWTP) and the current National Plan for Water Quality (NPWQ): Sanitation and Purification (2007–2015) as a tool for development of wastewater infrastructure to comply with water quality standards required by Directive 91/271/EEC and Royal Decree 1620/2007. Consequently, conformity with Directive 91/271/EEC reached 78% in 2007, compared with 41% in 1995 (Iglesias and Ortegal, 2008; Aragón *et al*., 2013). The remaining 22% is either in non-conformity or under construction status (Aragón *et al.*, 2013).

Barcelona Metropolitan Area covers 600 km^2 and includes more than 30 municipalities, with a total population close to 3.5 million people, which is about 50% of the total population of Catalonia (currently estimated at 7.4 million) (Mujeriego *et al.*, 2008). The treatment plant for wastewater from Barcelona metropolitan region was upgraded in 2002 to include biological secondary treatment using activated sludge and tertiary treatment of coagulation-flocculation, filtration, UV disinfection, post-disinfection and oxygen saturation for a volume of 14 400 m^3 wastewater per hour (Cazurra, 2008). The biological treatment combines anoxic, anaerobic and aerobic zones (Cazurra, 2008). The plant produces wastewater with the quality summarised in Table 8 (P. Aguiló, 2011). This wastewater is suitable for environmental flow injection; ≤10mg BOD_5/L, <5 NTU for turbidity, < 10 CFU/100mL of faecal coliforms, <1 nematode egg, >0.6 mg/L residual chlorine and ≥7.5 mg/L dissolved oxygen (Cazurra, 2008).

Table 8. Effluent quality at Barcelona wastewater treatment plant (P. Aguiló, 2011).

		EFFLUENT	
Parameter	**Units**	**Sampling event 1**	**Sampling event 2**
TSS	mg/L	3.0	5.5
BOD5	mgO2/L	<3	<3
COD	mgO2/L	22	44
Turbidity	NTU	1.0	2.0
N-NH4	mg/L	1.1	3.9
N-NO3	mg/L	3.5	6.6
TN	mg/L	6.9	9.8
TP	mg/L	0.7	2.0
Escherichia coli	MPN/100mL	<1	<1
Faecal coliforms	MPN/100mL	<1	<1
Helminth eggs	Ova/10L	<1	<1
Legionella spp.	CFU/L	<100	<100
Legionella pneumophila	CFU/L	<100	<100

In another study examining the presence of pathogens, bacteria and protozoa in treated wastewater, Mosteo *et al*. (2013) surveyed effluent wastewater from five treatment plants in the region of Navarra in Spain. All treatment plants disposed of their effluent to the river Ebro, from which water is reused. The types of treatments in the selected plants are summarised in Table 9 (Mosteo *et al.*, 2013). The study revealed that the physical and chemical parameters of the treated wastewater (Table 10) are more or less in compliance with Royal Decree 1620/2007 and Directive 91/271/EEC, with some exceptions for turbidity and solids in treatment plants 1 and 2. However, the pathogen content of the effluent of all these treatment plants places restrictions on its use. With the current pathogen content (Table 11), reuse of the effluent is limited to applications where there is no contact with humans or crops eaten raw.

Table 9. Types of treatment systems in five wastewater plants in Navarra, Spain, studied by Mosteo *et al.* (2013).

Plant	Inflow m^3/d	Primary treatment	Secondary treatment	Tertiary treatment
1	2 129	Grit and grease separation, sedimentation	Trickling filter	Natural lagoons
2	16 734	Screen, grit and grease separation, sedimentation	Trickling filter	–
3	361	Screen, sedimentation	Trickling filter	Natural lagoons
4	983	Screen, anoxic reactor	Activated sludge	–
5	3400	Screen, grit and grease separation, anoxic reactor, sedimentation	Aerated trickling filter	–

Table 10. Physical and chemical parameters of the final effluent from the five wastewater treatment plants in Navarra, Spain, studied by Mosteo *et al.* (2013).

Plant	Conductivity (µS/cm)	Turbidity (NTU)	SS (mg/L)	COD (mg/L)	BOD (mg/L)	DO (mg/L)
1	3220±0.5	34± 0.2	56±5.2	111±1.0	16.4±1.8	2.7± 0.1
2	1867±0.5	123± 0.2	52±5.2	60±1.0	17.5±1.8	3.1± 0.1
3	1086±0.5	1.74± 0.2	4±5.2	77±1.0	15.3±1.8	6.9± 0.1
4	2950±0.5	34.7± 0.2	32±5.2	62±1.0	45.4±1.8	3.5± 0.1
5	832±0.5	5.43± 0.2	20±5.2	50±1.0	29.5±1.8	5.7± 0.1
Royal Decree 1620/2007		2-15	10-35			
Directive 91/271/EEC			35-60	125	25	

DO: Dissolved oxygen

Table 11. Concentration of pathogenic bacteria in the final effluent from the wastewater treatment plants in Navarra, Spain, studied by Mosteo *et al.* (2013).

Concentration (CFU/100mL)	Plant 1	Plant 2	Plant 3	Plant 4	Plant 5
Escherichia coli	3.05 ± 0.5 × 105	7.35 ± 0.3 × 105	6.00 ± 0.2 × 102	1.36 ± 0.06 × 106	1.90 ± 0.1 × 105
Enterococcus spp.	<1	5.80 ± 0.08 × 104	1.20 ± 0.01 × 101	3.10 ± 0.03 × 105	7.20 ± 0.06 × 104
Pseudomonas spp.	1.16 ± 0.5 × 105	1.60 ± 0.9 × 105	1.60 ± 0.1 × 104	2.30 ± 0.09 × 104	2.77 ± 1.3 × 104
Staphylococcus aureus	5.30 ± 1.0 × 103	2.00 ± 0.5 × 104	2.20 ± 0.6 × 104	1.07 ± 0.3 × 105	3.30 ± 0.8 × 104
Clostridium perfringens	<1	1.64 ± 0.4 × 103	5.40 ± 0.1 × 101	1.40 ± 0.2 × 103	8.40 ± 0.1 × 102
Salmonella spp.	0	0	0	0	0
Legionella spp.	0	0	0	0	0

Beside the conventional pollutants usually found in wastewater (degradable organics solids and bacteria), chemical input from households and industrial activities to the sewerage system result in wastewater pollution with persistent organic compounds (POC), also referred to as priority pollutants (Martí *et al.*, 2011). These include compounds belonging to pesticides, polycyclic aromatic hydrocarbons (PAH), phenolic compounds, volatile organic compounds (VOD) and pharmaceuticals and personal care products (PPCPs). It should be pointed out that the occurrence and concentrations of POC are significant when wastewater is used for irrigation. Barco-Bonilla *et al.* (2013) surveyed the occurrence of 226 compounds belonging to the aforementioned types of pollutants in the effluent from 13 wastewater treatment plants in the arid-semi and arid zone of south-east Spain. The survey revealed ubiquitous occurrence of aldrin, pentachlorobenzene, o,p′-DDD and endosulfan lactone, which belong to banned types of pesticides. The same study reported up to 89.7 μg/L of 4-tert-octylphenol at all wastewater plants surveyed (Barco-Bonilla *et al.*, 2013). The concentrations of POC found in that study are summarised in Table 12. Based on the results obtained from monitoring of organic compounds and the fact that the sampling area is in a province with high agricultural activity, Barco-Bonilla *et al.* (2013) concluded that PAHs are the most predominant organic pollutants. The occurrence of 4-tert-octylphenol in high concentrations is of high environmental significance because of its oestrogenic and mutagenic activity.

Table 12. Average concentrations of organic pollutants (μg/L) in the effluent from 13 wastewater treatment plants in Andalucia, Spain (Barco-Bonilla *et al.*, 2013).

Sampling date	**7/04/2011**		**30/05/2011**		**12/07/2011**	
Compound	**Average**	**max**	**Average**	**max**	**Average**	**max**
Non-polar pesticides						
2-Phenylphenol	0.79	1.34	0.26	0.6	0.06	0.07
Alachlor	0.03	0.04	0.05	0.05	0.10	0.12
Aldrin	0	–	0.12	0.12	0	–
Chlorfenvinphos	0.15	0.26	0.08	0.2	0.12	0.24
Endosulfan lactone	0.10	0.11	0.10	0.16	0.09	0.14
Ethoprophos	0.06	0.09	0.05	0.08	0.06	0.18
o,p′-DDD	0	–	0	–	0.03	0.03
Pentachlorobenzene	0.14	0.14	0.13	0.13	0	–
Procymidone	0	< LOQ	2.75	5.35	0.15	0.15
Polar pesticides						
Atrazine	0.04	0.04	0	–	0	–
Diuron	0.25	0.38	0.08	0.13	0.09	0.27
Linuron	0.16	0.17	0.12	0.14	0.14	0.37
Sebuthylazine + ter-butylazine	0.10	0.25	0.03	0.03	0.08	0.22
Terbumetone	0	< LOQ	0.03	0.03	0.02	0.02
PAH						
Benzo[a]pyrene	0.1	0.1	0	–	0	–
Fluoranthene	0.06	0.14	0.01	0.01	0	–
Fluorene	0.25	0.68	0.06	0.12	0.05	0.06
Phenanthrene	0.16	0.49	0.04	0.07	0.04	0.06
Pyrene	0.06	0.15	0.01	0.02	0.03	0.03
Phenolic compounds						
2,4,5-Trichlorophenol	0.09	0.09	0.05	0.08	0.06	0.1
2,4,6-Trichlorophenol	0.11	0.16	0.08	0.14	0.06	0.1
4-Tert-octylphenol	0.21	0.37	7.56	89.74	0.10	0.25
Pentachlorophenol	0	–	0.04	0.06	0	< LOQ
1,3,5-Trichlorobenzene	0.18	0.18	0.13	0.15	0	–
Benzene	0	< LOQ	0.14	0.17	0	–
Ethylbenzene	0.11	0.11	0.41	0.41	0	–
m-Xylene + p-xylene	0.15	0.15	0.18	0.81	0.11	0.11
o-Xylene	0.13	0.13	0.27	0.27	0	< LOQ
VOCs						
Toluene	0.27	0.31	0.32	0.62	0.23	0.32
Trichloroethylene	0	< LOQ	0.14	0.21	0	–

LOQ: Limit of quantification

Another survey of priority pollutants by Martí *et al.* (2011) in the Comunidad Valenciana coastal region of Spain detected 36 organic pollutants, including 26 POCs, although many of them occurred at low frequency (Table 13). Moreover, 13 compounds belonging to VOCs, organochlorinated pesticides, phthalates and tributyltin compounds occurred at frequency higher than 20% (Martí *et al.*, 2011). Octylphenol, pentachlorobenzene, DEHP and TBT exceeded the environmental quality standard annual average concentration. Not surprisingly, the most frequent contaminants determined in coastal waters were also present in wastewater treatment plant effluents, as shown in Table 13 (Martí *et al.*, 2011).

Table 13. Frequency of occurrence, concentration (µg/L) and environmental quality standards of priority pollutants in surface water and wastewater in Valenciana, Spain (Martí *et al.*, 2011).

	Surface water			EQS		Wastewater effluent		
	%	**median**	**max**	**AAC**	**MAC**	**%**	**median**	**max**
Phenols								
4-Nonylphenol	10	<	0.01	0.3	2	7	<	0.01
Octylphenol	13	<	0.078	0.01	–	38	<	2.4
t-Nonylphenol	16	<	0.13	–	–	15	<	0.79
Benzene	51	0.01	0.3	8	50	76	0.03	44
Carbon-tetrachloride	33	<	4	12	–	50	0.75	69
1,2-Dichloroethane	0	<	<	10	–	1	<	1
Dichloromethane	6	<	0.003	20	–	29	<	0.23
Tetrachloroethylene	3	<	5	10	–	46	<	36
Trichloroethylene	33	<	4	10	–	48	<	13
1,2,3-Trichlorobenzene	10	<	0.015	0.4	–	45	<	0.109
1,3,5-Trichlorobenzene	5	<	0.005	0.4	–	19	<	0.09
1,2,4-Trichlorobenzene	8	<	0.041	0.4	–	44	<	0.109
VOC								
Trichloromethane	2	<	1	2.5	–	39	<	44
Toluene	100	0.17	1.6	–	–	70	0.1	12
o-Xylene	40	<	0.05	–	–	54	0.01	1.4
m,p-Xylene	96	0.05	0.27	–	–	64	0.03	2.8
Etylbenzene	78	0.01	0.22	–	–	38	<	2.3
Chlorobenzene	6	<	0.01	–	–	1	<	0.01
1,2-Dichlorobenzene	20	<	0.08	–	–	43	<	3
1,3-Dichlorobenzene	0	<	<	–	–	23	<	1.4
1,4-Dichlorobenzene	8	<	0.05	–	–	29	<	2.5
Organochlorinated pesticides								
Alachlor	9	<	0.014	0.3	0.7	5	<	0.0015
ldrin	2	<	0.003			1	<	0.0015
Dieldrin	6	<	0.0026	∑0.005		2	<	0.0015
Endrin	3	<	0.0002			11	<	0.0141
Isodrin	6	<	0.005			4	<	0.005
Endosulfan	9	<	0.0019	0.0005	0.004	18	<	0.13
Hexachlorobenzene	14	<	0.002	0.01	0.05	5	<	0.005
Hexachlorobutadiene	14	<	0.002	0.1	0.6	10	<	0.01
Hexachlorocyclohexane	30	<	0.0083	0.002	0.02	58	0.003	0.124
DDT	4	<	0.002	0.025	–	0	<	<
Pentachlorophenol	7	<	0.003	0.4	1	19	<	0.148
Pentachlorobenzene	10	<	0.007	0.0007	–	8	<	0.069
BDE								
Brominated diphenylether	3	<	0.0001	0.0002	–	2	<	0.005
SCCP								
C10–13 Chloroalkanes	0	<	<	0.4	1.4	0	<	<
Triazine herbicides								
Atrazine	0	<	<	0.6	2	0	<	<
Simazine	0	<	<	1	4	2	<	4
Trifluralin	0	<	<	0.03	–	0	<	<

Terbutilazine	0	<	<	–	–	2	<	2.5
Ametrine	0	<	<	–	–	1	<	0.2
Urea herbicides								
Diuron	0	<	<	0.2	1.8	1	<	0.5
Isoproturon	0	<	<	0.3	0.1	1	<	20
Organophosphorus pesticides								
Chlorfenvinphos	0	<	<	0.1	0.3	0	<	<
Chlorpyrifos	0	<	<	0.03	0.1	0	<	<
Phthalates								
Di(2-ethylhexyl) phthalate	57	0.25	15	1.3	–	32	<	0.25
Diethyl phthalate	21	<	20	–	–	17	<	29
Dibutyl phthalate	35	<	0.3	–	–	45	<	0.9
PAH								
Anthracene	0	<	<	0.1	0.4	0	<	<
Fluoranthene	0	<	<	0.1	1	0	<	<
Naphthalene	0	<	<	1.2	–	2	<	0.4
Benzo(a)pyrene	0	<	<	0.5	1	0	<	<
Benzo(b)fluoranthene	0	<	<	0.03		0	<	<
Benzo(g,h,i)perylene + indeno (1,2,3-cd)pyrene	0	<	<	0.002	–	0	<	<
Dibenzo(a h)anthracene	0	<	<	–	–	2	<	0.005
TBT								
Tributyltin compounds	28	<	0.026	0.0002	0.0015	NA	NA	NA

EQS: Environmental quality standards
AAC: Annual average concentration
MEC: Maximum concentration
NA: Not analysed

Recently, concerns have been expressed regarding the occurrence and fate of PPCPs in wastewater disposed of in water bodies in Spain, due to the negative effects of pharmaceuticals on aquatic life. Rosal *et al.* (2010) conducted a survey for 84 pollutants, mainly pharmaceuticals, in the inflow and outflow of the secondary clarifier of a wastewater treatment plant located in Alcalá de Henares (Madrid). The treatment is accomplished by activated sludge with biological nitrogen and phosphorus removal. Wastewater samples were collected every month for a one-year period. The plant treats a mixture of domestic and industrial wastewater with a nominal capacity of 3000 m^3/h of raw wastewater. The study revealed that paraxanthine, caffeine and acetaminophen were the main pollutants found in concentrations greater than 20 mg/L. N-formyl-4-amino-antipiryne and galaxolide were also measured at the mg/L level. Beta-blockers (atenolol, metoprolol and propanolol); lipid regulators (bezafibrate and fenofibric acid); antibiotics (erythromycin, sulfamethoxazole and trimethoprim); anti-inflammatories (diclofenac, indomethacin, ketoprofen and mefenamic acid); an anti-epileptic (carbamazepine) and an antacid (omeprazole) were 20% removed in the treatment plant. Table 14 shows the concentrations of the PPCPS observed. There is almost no information about the allowable concentration of PPCPs in the environment, and hence it is difficult to assess the severity levels of these pollutants. Nonetheless, the documented harmful effects of many PPCPs in aquatic life (Fatta-Kassinos *et al.*, 2011; Kvarnryd *et al.*, 2011; Chen *et al.*, 2013) necessitate development of efficient wastewater processes for their removal.

Table 14. Concentrations of pharmaceuticals in the effluent wastewater of Alcala treatment plant in Spain (Rosal *et al.*, 2010).

Compound	Effluent concentration (ng/ L) Maximum	Average	Removal Efficiency (%)
N-formyl-4-amino-antipiryne (4-FAA)	27 444	5593	68.2
N-acetyl-4-amino-antipiryne (4-AAA)	6745	4489	46.1
Ciprofloxacin	5692	2378	57
Gemfibrozil	5233	845	76
Galaxolide	2766	1225	87.8
Atenolol	2438	1025	14.4
4-aminoantipyrine (4-AA)	2253	676	55.4
Naproxen	2208	923	60.9
Paraxanthine	1796	836	96.9
Hydrochlorothi-azide	1702	1176	53.2
Ofloxacin	1651	816	64.1
Caffeine	1589	1176	94.9
4-methylaminoan-tipyrine (4-MAA)	1098	291	66.9
Ranitidine	942	360	31.2
Fluoxethine	929	223	61.9
Omeprazole	922	334	8.5
Erythromycin	760	331	4.3
Furosemide	666	166	59.8
Ibuprofen	653	135	95
Ketorolac	607	228	43.9
Ketoprofen	539	392	11.2
Triclosan	512	219	74.5
Diclofenac	431	220	5
Sulfamethoxazole	370	231	17.3
Codeine	319	160	69.3
Tonalide	315	146	84.7
Bezafibrate	280	128	9.1
Carbamazepine	173	117	9.5
Mefenamic acid	163	138	1.8
Nicotine	158	81	98.7
Trimethoprim	148	99	5.1
Fenofibric acid	129	78	1.3
Metronidazole	127	55	38.7
Benzophenone-3	121	86	78.2
Clofibric acid	91	12	54.2
Diuron	81	42	61.5
Indomethacine	59	37	11.1
Antipyrine	58	27	32.8
Propanolol	57	36	1
Metoprolol	38	19	6.5
Acetaminophen	<LOQ	<LOQ	100

LOQ: Limit of quantification

5.2 Abu Dhabi Emirate

The Abu Dhabi Sewerage Service Company (ADSSC) currently owns, operates and maintains two main wastewater treatment plants, 24 small-scale wastewater treatment units, 236 pumping stations (80% in Abu Dhabi) and over 7400 km of sewer mains (66% in Abu Dhabi). ADSSC is also responsible for planning and implementing the system expansion required to support future growth (ACWUA, 2010). The two largest wastewater treatment plants, serving Abu Dhabi city and the surrounding metropolitan area, are the Mafraq and Al Ain Zakhar plants. They treat some 95% of the polluted wastewater collected by the sewer network, including trade and some industrial aqueous effluents (EAAD, 2009). The treatment plants use activated sludge (23% of plants), package plants (10%) and membrane bioreactors (3%) (Al-Mulla, 2011). The largest wastewater treatment plant in Abu Dhabi (the Mafraq plant) has an average daily flow of 360 000±16 000 m^3. The Mafraq plant consists of conventional activated sludge treatment followed by sand filters, chlorination and odour control for the liquid fraction and mesophilic anaerobic digestion for the sludge (EAAD, 2009).

The quality of the wastewater treated in the Mafraq plant (Table 15) is in compliance with the reuse standards suggested by the RSB (see Table 4). The only concern is the industrial development, which might increase the heavy metal loads to the wastewater treatment plant (EAAD, 2009).

Table 15. Quality of wastewater effluent from the Mafraq plant in Abu Dhabi. All parameters are in mg/L unless otherwise stated (adapted from Abu Dhabi Water Resources Master Plan; EAAD, 2009).

Parameter	Influent	Effluent	Parameter	Influent	Effluent
BOD	196	0.8	Nitrate	-	8.5
COD	300	5	Na	-	630
TSS	163	2	Ca	-	23.7
TDS	2338	2245	Total P	13	7
Conductivity (µS/cm)	4 600	4200	Chloride	1376	1282
Turbidity (NTU)	-	1.6	Sulphate	-	7.2
TOC	-	-	Residual Cl2	20	2.3
Alkalinity	223	48	Coliforms (CFU/100mL)	-	4
T-Hardness	460	450	E-Coli (CFU/100mL)	-	1
Ammonia-N	28	0.4			

As for the occurrence of PPCPs in wastewater in Abu Dhabi, Salem *et al.* (2012) detected 11 β-blockers and β-agonists in 60 samples of wastewater effluent from both the Abu Dhabi and Al Ain wastewater treatment plants. β-Blockers are used to treat cardiovascular diseases and β-agonists are used in the treatment of respiratory diseases. Salem *et al.* (2012) found five β-blockers and one β-agonist in Al Ain and Abu Dhabi wastewaters at average concentrations of 3.44–19.05 pg/mL (Table 16). Atenolol was detected at higher average concentrations (range 125.60–234.28 pg/mL). The study also showed high stability of the compounds in the wastewater for up to 6 days retention time (Salem *et al.*, 2012). The authors concluded that the wastewater treatment process used (activated sludge) is not adequate for the removal of these compounds. No published data were available on the occurrence of POP in wastewater effluent in Abu Dhabi.

Table 16. Concentration (pg/mL) of β-blockers and β-agonists in the effluent wastewater from two treatment plant in Abu Dhabi (Salem *et al.*, 2012).

Compound	Abu Dhabi treatment plant Average	Abu Dhabi treatment plant STDEV	Al Ain treatment plant Average	Al Ain treatment plant STDEV
Terbutaline	11.11	5.78	7.53	5.77
Atenolol	125.6	43.04	234.28	40.24
Metoprolol	10.96	5.25	6.56	4.02
Acebutolol	7.36	4.15	12.18	3.78
Labetalol	19.05	58.53	3.44	2.45
Propranolol	12.36	7.87	3.92	4.54

Most of the sludge in Abu Dhabi is used for composting, although a small percentage goes to landfill (EAAD, 2009). According to the Environmental Agency of Abu Dhabi, future strategies are being planned to convert the digested sludge into pellets for soil fertilisation (EAAD, 2009).

6 Other Aspects of Wastewater Treatment and Use

An important criterion for assessing reclaimed wastewater use projects is the capability and willingness of users to accept reclaimed wastewater in the quantities estimated and to bear the price or costs of treatment (FAO, 2010). Thus, it may be necessary to conduct a dialogue with potential users of reclaimed wastewater when planning new or upgraded wastewater facilities in order to identify possible win-win scenarios for all stakeholders. Education of the public may help to overcome fears about reclaimed wastewater use, especially those relating to public health and water quality.

Implementation of sustainable reclaimed wastewater use must not only comply with reuse standards and regulations, but must also meet environmental, socio-cultural and economic needs. In this regard, Molinos-Senante *et al.* (2011) concluded that assessments of the economic feasibility of wastewater treatment and reuse projects should include both market value and environmental benefits. In the same study, Molinos-Senante *et al.* (2011) performed cost-benefits analyses of wastewater use in 13 treatment plants in Spain, including the cost of environmental benefits, and found that prevention of nitrogen and phosphorus discharge was the greatest environmental benefit. However, assessment of environmental benefits, especially in monetary terms, is difficult, if not impossible. Reclaimed wastewater use reduces the demand for freshwater and it can reduce the need for artificial fertilisers, while in many applications the quality of reclaimed water is superior to that of e.g. surface water.

Reclaimed wastewater use systems also have to ensure secure water quality standards without any risks for end-user contamination. This means that systems for potable and non-potable water have to be clearly separated with robust and vital barriers. Another crucial aspect is that of online and real-time water quality monitoring of reclaimed wastewater use systems. Various quality parameters, such as pathogen and virus concentrations, have to be implemented to ensure the safety of reclaimed wastewater use.

In developing future wastewater treatment technologies, in is necessary to go beyond wastewater purification and consider reducing the use of non-renewable energy, minimising waste generation and enabling nutrient recovery and resource recycling (Mo and Zhang, 2013). Both Spain and Abu Dhabi Emirate are endowed with a warm climate and long sunshine hours and thus integrating wastewater treatment with onsite energy generation, e.g. using solar energy or exchange heat from wastewater, might be beneficial and should be considered in wastewater facilities targeting these areas.

7 Conclusions

Reclaimed wastewater use has been recognised as one of the main ways to meet water requirements in all water-using sectors in a more sustainable way. There is just one water in the world. Reclaimed wastewater use can be seen as a renewable supply of water that helps to reduce water stresses by decreased use of freshwater and by reducing the pollution of aquatic environments. The main areas of future reclaimed wastewater use will be irrigation in agriculture, forestry and urban environments, industrial processes e.g. cooling or process water, and augmentation of natural water sources. The latter provides the possibility to meet the increasing water demands of society.

A prerequisite for reclaimed wastewater use is the existence of regulations and standards defining the quality of reclaimed wastewater and/or the technologies that have to be applied in order to reach the quality for various reuse applications. In areas with limited access to freshwater or environmental problems caused by overexploitation of natural water systems, such regulations have been introduced. Rather well-developed reuse regions, such as Spain and Abu Dhabi Emirate, have created their own standards, while general guidelines such as those from the WHO or the European Commission may be a starting point for areas that have no such framework for reclaimed wastewater use.

The case studies of Spain and Abu Dhabi Emirate showed that large proportions of treated wastewater are already being used today for irrigation. Treated wastewater is used for crop cultivation in Spain, while it is used for park irrigation in Abu Dhabi Emirate. Use of treated wastewater for forestry might be very relevant, as the case of Abu Dhabi illustrates. However, this example also indicates that public awareness, laws and regulations need to be established to limit the use of depleted freshwater sources for forestry and promote the use of treated instead. This illustrates that the standards and regulations for reclaimed wastewater use, as presented in this report, are only one component of successful reclaimed wastewater use. Education, awareness and involvement of all stakeholders are a fundamental prerequisite for reclaimed wastewater use. This is especially true as wastewater use schemes often may not be economically sound since the avoided damage to nature is impossible to value and because fresh water is free of charge or underprized.

Use of reclaimed wastewater for industry is not widespread in either Spain or Abu Dhabi Emirate. However, efficient wastewater treatment systems for industrial wastewater might lead to enhanced onsite use of wastewater in industrial facilities.

Much of the technology used for wastewater treatment is proven technology. In particular, the removal of conventional pollutants, such as easily degraded organics and solids, is generally efficient. Enforcement of regulations regarding the disposal and safe use of wastewater may generally enhance the quality of the wastewater, as has been observed in Spain. The hygiene quality of the treated wastewater is acceptable mainly when tertiary treatment and disinfection are applied. Removal of pathogenic bacteria is absolutely essential to allow the wastewater to be reused.

Hygiene-oriented treatments need to be considered when developing or upgrading existing treatment plants.

Contamination of wastewater with persistence organic pollutants (POP) including pesticides, PAHs and VOCs, is a concern in wastewater use, as the examples of Spain and Abu Dhabi Emirate show. Stringent treatment of industrial wastewater is needed to eliminate the POP contamination before it ends up in the municipal wastewater plant. In addition to this, advanced wastewater treatment might still be needed to complete the removal of such substances. Contamination of wastewater with pharmaceuticals is an emerging problem, and harmful effects of PPCPs for aquatic life have been documented. This necessitates the elimination of PPCP residues from wastewater effluents. However, regulations about allowable concentrations of PPCPs and acceptable risk levels are currently not available but are needed to push treatment utilities to adapt technologies for effective PPCP removal from wastewater.

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