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Wastewater reuse and risk: definition of key objectives

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Abstract

Wastewater reclamation holds promise as an important water resource as the desire to develop arid regions continues to place increasing demands on finite water resources. The debate surrounding the consumption of reclaimed wastewater finds risk managers pondering the question of what types of water quality standards might be set in order to provide the proper level of safety associated with the use of reclaimed wastewater. We propose quality categories for different reuses such as irrigation or indirect aquifer recharge with different requirements towards microbial and chemical parameters. Based on recent existing guidelines and risk estimations, microbial and chemical limits for each category were compiled. Since economic calculations are very important, analytical costs are included and measurements frequency is proposed. Biological parameters have to indicate all potential pathogenic organisms including viruses, bacteria and parasites from different origins. The selected biological indicator parameters most used in rules and regulations are coliforms and *E. coli*, indicating the occurrence of a former faecal contamination and the possible presence of all pathogens occurring in faeces of warm-blooded animals. In the case of wastewater reuse, biological parameters have to indicate all potential pathogens causing infection diseases and/or intoxication in all living beings including plants and animals. The large number of possible chemical parameters in relation with wastewater reclamation and reuse has to be adapted and minimized with respect to the origin of the sewage, the extent of the treatment process and the intended use. These parameters must cover a broad spectrum of toxicological and ecological risks as well as possible technical disorders. Risk assessment and risk management are also necessary.

Keywords: Risk assessment; Wastewater reuse; Microbiological and chemical parameters

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1. Introduction

Wastewater reclamation and reuse have been the subject of a number of studies dealing with water quality for some time, especially in relation to microbiological criteria. During the last decade, chemicals have also been incorporated into the oberservation panel, thus enlarging the number of parameters to be determined for safe reuse of wastewater.

Reclamation and reuse hazards are usually defined according to standards issued or recommended by local authorities or international agencies. When trying to study the rationale of such an approach, there are several inconsistencies, namely the adequacy of control parameters, a certain lack of definition of the appropriate sampling points, the number of samples and analysis necessary, and the cost of the analytical work.

In any case, if standards are to be met, it appears that planning steps, economic calculations, and social tasks are to be performed for successful reclamation and reuse practices. Then, it seems obvious that scenarios must be built for the correct comparison of the different possible alternatives, including all the data needed to reach a correct decision.

From the zero scenario (no reuse) to the theoretically more expensive one (reclamation or seawater desalination using reverse osmosis), adequate tools are to be used in order to help stakeholders to decide the best option for the increase of available water resources. Among the tools, decision support systems are the most useful for gaining good information, but other studies must also be undertaken to determine the necessary technologies and schemes. As health hazards are one of the main constraints for reuse, it appears that risk assessment, based on hazard calculations, is basic for several definitions in reclamation and reuse projects.

A discussion came up on the adequacy of the main parameters used (coliform-derived standards, nematode eggs), the suggested ones, the number of samples compulsory for the “legal” safe reuse, and on the price of the analytical work necessary to fulfil legal requirements. If preventive risk management concepts (mainly HACCP) are used, the number and periodicity of analysis are reduced to the established critical control points, which will decrease costs. Standards, HACCP systems, and good reuse practices must be considered in an integrated way in for efficient management of the reclamation practices. A final question is issued: can classical reclamation be competitive with other water sources if all the compulsory actions are performed?

2. Microbiological and chemical parameters concerning reclaimed wastewater reuse

The risks concerning reclaimed wastewater reuse can be classified into biological and chemical risks. The biological and chemical parameters of interest are described in more detail below.

2.1. Microbiological parameters

The increase of health hazards and concerns in relation to wastewater, the growing number of wastewater treatment facilities, and the need for obtaining additional water resources through wastewater reuse have forced the necessity of using more precise and sophisticated biological control tools for wastewater recycling. Due to the costs and complexity of analyzing actual pathogens, it should be considered [1] that wastewater professionals and regulators have relied for decades on traditional faecal indicators (Table 1) to predict potentially high pathogen levels being sufficient to guarantee high-quality standards.

The scientific community was always aware that detection and quantification of *E. coli* are not enough to define the quality of a certain wastewater treated, reclaimed, or discharged into the

Table 1
Types of waterborne pathogens and used indicators [2]

Waterborne pathogens	Indicators	Observations
Bacteria	*E. coli*, Faecal coliforms, Total coliforms, *Enterococcus fecalis*, *Staphylococcus aureus*, *Salmonella* spec., *Clostridium perfringens*, *Pseudomonas aeruginosa*, *Legionella pneumophila*	Faecal coliform (FC) determination is more usual; *E. coli* determination is slowly substituting FC. Other bacteria are used for bathing waters, groundwater, etc.
Viruses	Enterovirus, Hepatitis A virus Bacteriophages	An accepted indicator still does not exist. Bacteriophage is being studied in this sense.
Helminth–Nematode	Nematode eggs (*Ascaris*, *Trichuris*, *Ancylostoma* as indicated by the WHO)	Discouraging: many negative results in many countries. Egg viability is not required.
Other helminths (i.e., *Taenia*)	Unknown	In some cases important for risk related to animal health
Protozoa (includes *Giardia*, *Cryptosporidium*, *Amoeba*, *Balantidium*, etc.)	Unknown The presence of one of them could indicate the presence of the other	Analytical tools not well developed until now
Fungi, algal toxins	Unknown	Few cases detected

environment. Some pathogens are more resistant to conventional wastewater treatment (including chlorination) and its sources are not warm-blooded animal faeces. Therefore, *E. coli* is an insufficient tool to reflect the quality changes due to wastewater treatment processes, conventional or advanced, extensive or intensive. In addition, it does not permit the control of wastewater disinfection.

Otherwise, the long period of time needed to produce results is a negative feature in the analytical work, but not only related to *E. coli* determination. However, new molecular biological methods are under development that enable a faster determination of specific microorganisms [3]. It is necessary to define more suitable indicators in order to establish the biological quality of different types of wastewater (Table 1). For example *Enterococcus faecalis* and even spores of *Clostridium perfringens* are known to be more resistant against disinfection than *E. coli* and therefore may be used for its control. Otherwise, the current analysis using bacterial indicators detects only the quality of a wastewater single sample and not the constant quality during a given time.

Campos also reported on the difficulty of defining microbiological quality of the media that receive reclaimed wastewater, particularly the agricultural systems where reclaimed water is used for irrigation [4]. Plants, soil, groundwater, run-off and the atmosphere can and must be controlled separately from the reclaimed wastewater. Campos also indicated the need to establish and realize joint studies of all media implied in wastewater reuse systems. An additional difficulty is the lack of reference figures for the content of pathogen organism in media other than water.

As indicated previously, several groups of organisms are "determined" by using indicators (i.e., pathogen bacteria by *E. coli*), although others (i.e., *Giardia lamblia*) do not have useful indicators and must be determined directly (Table 2).

Table 2
Organisms usually determined in wastewater treatment, and reuse [2]

Type/organism	Usually/theoretically employed as	On research	Observations
Total coliforms	Bacterial indicator		Not widely used
Faecal coliforms/ *E. coli*	Faecal indicator	Faster methods	Most used method, despite the problems and discussions
Bacteriophage	Faecal indicator	Most suitable one	Somatic, F-specific and *Bacteroides fragilis* HSP40 and RYC2056 phages
Bacterial count	Indicator for aerobic, heterotrophic bacteria	Amount of DNA/RNA	Recovery of not more than 10%
Nematode eggs	Nematode and helminth indicator	Better concentration methods. Viability	Recovery of not more than 70%
Giardia lamblia	Direct detection of cysts	Better concentration and detection methods. Viability	In wastewater, false positives can be found in high numbers
Cryptosporidium parvum	Direct detection of oocysts	Better concentration and detection methods. Viability	In wastewater, false positives can be found in high numbers

Until now, indicator-based standards have been used to define a suitable reclaimed water quality. Nevertheless, it must be stated that the health risk related to reuse is defined by several aspects: the microbial agent, the human host, and the environment in which the infection process is mediated [5]. As it is the interaction of these components which produces human disease, risk is dependent on defining the exposed population, the microbial characteristics, and the environmental setting in which the exposure occurs. The human health risks associated with the ingestion of waterborne pathogens could be theoretically and numerically defined by using statistical models that calculate the probability of individual infection or disease as a result of a single exposure event. These types of calculations [6] could be a good tool when fully developed in the future.

It has been suggested in a WHO report [7] that the epidemiological method must be employed for determining health risks associated with reuse practices. Nevertheless, it seems not to be a good tool, as stated by Cooper and Olivieri [8]. It appears that traditional epidemiological methods are not sensitive enough to “tease out” cases that might be associated with recycled water from the background incidence of these ailments in the community.

2.2. Chemical parameters

Internationally, there is an increasing requirement for the inclusion of chemical parameters in guidelines or regulations concerning reuse of reclaimed wastewater. The main reason is that chemicals in low concentrations may show no direct toxic effects but do show long-term chronic effects or bioaccumulation. Environmental concerns are a further important factor because several organisms show high sensitivity to some chemicals. Several national irrigation regulations contain physicochemical or chemical parameters, but there is considerable variation among these guidelines, particularly regarding identifiable values and the limited parameters. Recent guidelines concerning wastewater reuse and irrigation

Table 3
Overview of the compiled chemical limits for reclaimed wastewater reuse from existing guidelines and proposed chemical limits depending on the specific use

Parameter/chemical category	Unit	1	2	3	4
		Private, urban and irrigation	Environmental and aquaculture	Indirect aquifer recharge	Industrial cooling
pH		6.0–9.5	6.0–9.5	7–9	7.0–8.5
BOD	mg /L	10–20	10–20		
COD (or TOC)	mg /L	100	70–100 (1)	70–100	70 (1)
Dissolved oxygen	mg/L	>0.5	>3	>8	>3
AOX	µg/L			25	
UV 254 absorbance	$\text{cm}^{-1}\times10^{3}$	30–70	30–70	10	
Electrical conductivity	µS/cm	3000	3000	1400	
TSS	mg/L	10	10		10
Active chlorine (only if chlorination)	mg/L	0.2–1.0	0.05		0.05
Total Kjeldahl N	mg/L	15–20	10–20		10
Ammonium-N	mg/L	2–20	1.5	0.2	1.5
Parameters of medium analytical frequency (monthly, once per year)					
Sodium absorption ratio (SAR)	$\text{mmol/L}^{0.5}$	5	5		
Na	mg/L	150	150–200		200
As	mg/L	0.1–0.02	0.1–0.02	0.005	
B (total)	mg/L	0.4–1.0	0.4–1.0	0.2	
Cd	mg/L	0.005	0.005	0.003	
Cr (total)	mg/L	0.1–0.01	0.1–0.01	0.025	
Cr III	mg/L	0.1	0.1		
Cr VI	mg/L	0.005	0.005		
Hg	mg/L	0.001–0.002	0.001–0.002	0.0005	
Pb	mg/L	0.1	0.1	0.005	
Nitrate	mg/L			25	
F (total)	mg/L	1.5–2.0	1.5–2.0		
Chloride	mg/L	250	250–400	100	400
Sulphate	mg/L	500	500	100	
Total P	mg/L	2–5	0.2		0.2
Surfactant (total)	mg/L	0.5	0.5		
Mineral oil	mg/L	0.05	0.05		
Parameters of low analytical frequency (once per year–once per 5 years)					
Al	mg/L	1–5	1–5		
Ba	mg/L	10	10		
Be	mg/L	0.1	0.1		
Co	mg/L	0.05	0.05		
Cu	mg/L	0.2–1.0	0.2–1.0		
Fe	mg/L	2	2		
Li	mg/L	2.5	2.5		
Mn	mg/L	0.2	0.2		

Table 3, continued

Parameter/chemical category	Unit	1	2	3	4
		Private, urban and irrigation	Environmental and aquaculture	Indirect aquifer recharge	Industrial cooling
Mo	mg/L	0.01	0.01		
Ni	mg/L	0.2	0.2	0.01	
Se	mg/L	0.01–0.02	0.01–0.02		
Sn	mg/L	3	3		
Th	mg/L	0.001	0.001		
V	mg/L	0.1	0.1		
Zn	mg/L	0.5–2.0	0.5–2.0		
CN (total)	mg/L	0.1–0.05	0.1–0.05		
Pesticides (total)	mg/L	0.05	0.05		
Pesticides and their metabolites, per subst. (country specific)	mg/L			0.0001	
Pentachlorophenol	mg/L	0.003	0.003		
Synthetic complex-forming subst., per subst. (e.g., EDTA)	mg/L	0.0001	0.0001	0.0001	
Chloride solvent (total, if AOX > limits)	mg/L	0.04	0.04		
Tetrachloroethylene, trichloroethylene	mg/L	0.01	0.01		
Disinfection (by)products (only if chlorination)					
NDMA	mg/L	0.0001[a]		0.0001[a]	
Trihalomethane	mg/L	0.03	0.03		
Aldehyde (total)	mg/L	0.5	0.5		
Aromatic organic solvent (total)	mg/L	0.01	0.01		
Benzene	mg/L	0.001	0.001		
PAH (total)	mg/L				
Benzene(a)pyrene	mg/L	0.00001	0.00001		
Phenol (total)	mg/L	0.1	0.1		
Endocrine active substances (E-Screen)	mg/L	0.0001[a]	0.0001[a]	0.0001[a]	
Pharmaceuticals (per subst., e.g., carbamazepine, X-ray contrast)	mg/L	0.0001[a]	0.0001[a]	0.0001[a]	

[a] Proposed value.

have been developed in Italy and Israel [9–11]. These are more specific concerning chemical parameters than former existing regulations in other parts of the world.

There are many physical and chemical parameters that can be determined in relation to wastewater reclamation and reuse: from the simplest ones (pH, EC) to the most complicated and expensive (endocrine disruptors) ones as shown in Table 3. Simple parameters such as salinity, *E. coli*, turbidity, TSS, organic matter, DOC and others, N- and P-related can give useful information depending on the final use of reclaimed water. They can give information about

Table 4
Cost calculation and proposed measuring frequency of physicochemical and chemical quality parameters

Parameter	Example/indicators	Measuring frequency	Costs	Importance for chemical cat. (Table 5)
Physico-chemical	pH, EC, turbidity, TSS, colour	+++	Very low	1–4
	Sodium absorption ratio (SAR), UV 254	++		1–4
Organic sum parameters	COD (TOC, DOC), BOD, DO, AOX	+++	Low–medium	1–4
		++		1–4
Nutrients, minerals	Total-N, NH_4^+-N, Total-P, NO_3^-	+++	Low	1–4
	SO_4^{2-}, CN^-, F^-, Cl^-	++	Low	1–4
Residual chlorine	Cl_2 (if chlorination)	+++	Low	1, 2, 4
	Disinfection products/by-products (e.g., NDMA)	+	Very high	1, 3
(Heavy) metals	As, Cd, Cr(III,VI), Hg, Pb, B, Al, Ba, Be, Co, Cu,	++	Medium	1, 2, 3
	Fe, Li, Mn, Mo, Ni, Se, Sn, Th, V, Zn	+	Medium	1, 2
Organic micro-pollutants	Surfactants	++	Medium	1, 2
	Mineral oil	++	Medium	1, 2
	Pesticides (e.g., Diuron; 2,4-D)	+	High	1–3
	Complex-forming substances (e.g., EDTA)	+	High	1–3
	Chloride solvents (if AOX > limit, e.g., TCE)	+	High	1, 2
	Aldehyde	+	Medium	1, 2
	Aromatic organic solvents (e.g., benzene)	+	High	1, 2
	PAHs (e.g., benzo(a)pyrene)	+	High	1, 2
	Phenols	+	Medium	1, 2
	Pharmaceuticals (e.g., carbamazepine, x-ray contrast media, sulfamethoxazole), endocrine disruptors (E-Screen)	+	Very high	1–3

Frequency: +++, permanently–weekly; ++, monthly– once per year; +, once per 1–5 years.
Costs per analysis: very high, >€200; high, €60–200; medium, €20–60; low, €6–20; very low, <€6.

the quality and success of the treatment process and thereby indicate the elimination rate of other difficult parameters such as nematode eggs or organic pollutants. Most of them are already included in existing guidelines for all final uses.

Depending on the origin of the wastewater and the intended use, in addition, different, more specific parameters are required. The high number of parameters may be reduced by risk assessment approaches in order to identify the most critical ones. Furthermore, to minimize analytical costs, suitable indicator substances or indicator effects should be identified and a suitable monitoring strategy integrated in an adequate HACCP concept must be developed [12].

It is well accepted that the concentration of heavy metals in wastewater effluent can be critical, especially in industrial regions. Their chemical analyses are sometimes difficult due to their speciation. For some uses like crop irrigation the determination of certain heavy metals such as the carcenogenic Pb and Hg is advised at regular time intervals.

In addition, an extensive list of organic micropollutants has been discussed in recent years since it is known that a significant number of trace chemical contaminants persist in municipal

Table 5
Microbial and chemical water quality categories for different final uses of reclaimed wastewater (adapted from CEDEX, [21])

Microbial category	Chemical category [12]	Specific final use
I	1	Residential uses: private garden irrigation, toilet flushing, home air conditioning systems, car washing.
	No category[a]	Aquifer recharge by direct injection.
II	1	Bathing water.
III	1	• Urban uses and facilities: irrigation of open access landscape areas (parks, golf courses, sport fields, etc.). Street-cleaning, fire-fighting, ornamental impoundments and decorative fountains. • Irrigation of greenhouse crops. • Irrigation of raw consumed food crops. Fruit trees sprinkler irrigated. • Unrestricted irrigation.
IV	1	• Irrigation of pasture for milking or meat animals. • Irrigation of industrial crops for canning industry and crops not raw-consumed. • Irrigation of fruit trees except by sprinkling. • Irrigation of industrial crops, nurseries, fodder, cereals and oleaginous seeds.
	2	Impoundments, water bodies and streams for recreational use in which the public's contact with the water is permitted (except bathing).
V	1	Irrigation of forested areas, landscape areas and restricted access areas. Forestry.
	2	Aquaculture (plant or animal biomass).
	3	Aquifer recharge by localized percolation through the soil.
VI	2	Surface water quality, impoundments, water bodies and streams for recreational use in which the public's contact with the water is not permitted.
VII	4	Industrial cooling, except for the food industry.

[a] Direct aquifer recharge should be drinking-water quality; potable water should not be produced from reclaimed wastewater without advanced tertiary treatment such as reverse osmosis or percolation through the soil (i.e., indirect aquifer recharge). For microbial categories, see Table 6.

wastewater after conventional treatment processes [13,14]. Some of these chemicals are known or suspected of deleterious implications to the environment, but only part of them is known to be related with toxicity to humans. There is evidence that endocrine-disrupting chemicals such as the synthetic estrogen 17-α-ethinylestradiol, are discharged via treated sewage effluents and occur in the environment in concentrations that may detrimentally affect aquatic organisms [15,16]. In addition, it is known that several persistent organic pollutants including some pesticides or polar pharmaceutics may also enter groundwater by infiltration through the soil passage, during processes such as bank filtration [17] or even permeate through reverse osmosis treatment.

Until now, only in some cases, organic micropollutants are included in the recommendations such as total and mineral oils, persistent substances, and pesticides. Especially for recharge of groundwater for drinking water purposes and for agricultural use, it is important to take these pollutants into account. On the other hand, their determination is very expensive and it is difficult to find an indicator for such a huge number of

Table 6
Cost calculation of microbiological analysis

Parameter	Cost	Important for microbial category (Table 5)
Legionella	High	I, III–V
E. coli and similar	Very low	I–VII
Enterococci (*Salmonella*)	Low	I–VII
Nematode eggs	Medium	I–VII
Taenia	Medium	V
Giardia and *Cryptosporidium*	High	I–III, VI
Bacteriophage	Low	I–III, VI
Enterovirus	High	I–III, VI–VII

Costs per analysis: Very high, > €200; high, €60–200; medium, €20–60; low, €6–20 €; very low, <€6.

substances with different properties and different origin. Some typical compounds or indicator substances are listed in Table 4. Since carbamazepine and x-ray contrast media are known to be very persistent during wastewater treatment [18] and also groundwater recharge [19], they could be used as possible indicator substances. It is proposed to measure all endocrine active substances as endocrine activity using a bioassay such as E-Screen [20].

2.3. Microbial and chemical categories for reclaimed wastewater reuse

There are different possible fields of application for reclaimed wastewater reuse; therefore, different water quality categories are needed. In Table 5 use-depending water qualities concerning the microbiological and chemical parameters are presented. Seven microbial water qualities, according to the Spanish recommended regulation [21], and four chemical water qualities were proposed [12]. In contrast to the microbial risks, no explicit differences in chemical water qualities are required by reclaimed wastewater irrigation of crops that are consumed raw or cooked. Other categories (e.g., microbial category V) include several uses that need the same microbial quality but different chemical requirements. The uses of reclaimed wastewater are so different from each other, except the varying irrigation categories, that separate water distribution networks with different water quality must be built. However, to implement reclaimed wastewater reuse for private use on a different scale, only one additional pipeline should be installed. Therefore, the water distributed by this pipeline should meet the highest water quality that is required for private uses (in this case: private garden irrigation). If it is not possible to install the required distribution networks, the use with the highest water quality demand fixes the water quality of the pipeline.

The discussion arises whether reclaimed wastewater should be used for direct aquifer recharge, as proposed by the Spanish recommended regulation [21] or not. For human health protection and maximum chemical clarity preservation, drinking water supplementation should only be permitted after advanced tertiary treatment (membrane processes, reverse osmosis) and other barriers such as percolation through the soil.

2.4. Analytical costs

The calculated analytical costs concerning the microbial parameters are presented in Table 6. The determination of *Legionella*, *Giardia*, *Cryp-*

Table 7
Overview of the compiled and estimated microbiological limits for reclaimed wastewater reuse I (bacteria)

Use	Total bacteria (cfu/mL)	Faecal coliforms[a] (cfu/100 mL)	*Clostridium perfringens* (cfu/mL)	*Legionella* (cfu/100 mL)	Enterococci (cfu/100 mL)	*Salmonella* (cfu/mL)
I	<1,000–<10,000	Abs	Abs–20	<100	Abs	Abs–1,000
II	<1,000	<20–<1,000	Abs–10	—	<1,000	Abs–1,000
III	<10,000	Abs–<1,000	<1	<100	<20	Abs–1,000
IV	<10,000–<100,000	Abs–<10,000	<10	Abs	<1,000	<1
V	<100,000	Abs–<10,000	<100	—	<10,000	<0.1
VI	<10,000	<200–<10,000	<1	—	<20	Abs–1,000
VII	<10,000	Abs–<10,000	<10	Abs–<100	<1,000	<1

[a] or *E. coli*. cfu = colony forming units; Abs = absent.

Table 8
Overview of the compiled and estimated microbiological limits for reclaimed wastewater reuse II (not bacteria)

Use	Enteroviruses (pfu/L)	Coliphages (pfu/L)	*Cryptosporidium* and *Giardia* (cyst/50 mL)	Nematode eggs (eggs/L)	*T. saginata* (egg/L)	*T. solium* (egg/L)
I	Abs–10	<1	<1	<1–10	—	—
II	Abs–10	<1	<1	<1	—	—
III	<1–<100	<1,000	<10	<1	—	—
IV	—	—	—	<1	—	—
V	—	—	—	<1	<1	<1
VI	<100	<1,000	<10	<1	—	—
VII	<1–0.04	—	—	<1	—	—

pfu = plaque forming units; Abs = absent.

tosporidium and enteroviruses are the most expensive parameters. Otherwise, *E.coli* analysis presents a very low price for quantification (less than €6 per analysis).

Concerning the control frequency of the specified chemical parameters, the simple and inexpensive parameters such as electrical conductivity, turbidity and COD can be measured in frequent time intervals, whereas the expensive indicator compounds of micropollutants or heavy metals need rare monitoring, e.g., once a year. In addition, the analytical effort could depend on the reclamation system. Large plants or even demonstration projects should perform a greater monitoring program including several micropollutants than small reclamation facilities.

2.5. Proposed microbial and chemical limits for reclaimed wastewater reuse

According to the recent existing guidelines (e.g., Italy, Israel, Catalonia in Spain), the important microbiological parameters with limits or limit ranges are compiled in the Table 7 (bacteria) and Table 8 (other microorganisms) relating to the final use of reclaimed wastewater. In accordance to recent guidelines [9–11] and industrial principles [22], the following chemical limits for reclaimed wastewater reuse were set (Table 3). Important values not mentioned in the guidelines were estimated, including ecological effect concentrations described in the literature.

3. Risk assessment

The main objective of risk assessment is to identify the risks and to evaluate scientific information that is available to decide whether a hazard exists and what the magnitude of that hazard may be [23]. The estimates calculated by the risk assessment method are used as a basis for deciding on actions to eliminate, reduce or otherwise manage the risk under consideration. In the future, health risk management and assessment tools have to be established for reclaimed water quality standards. A full version of existing rules and data on epidemics and microbiological quality, and also toxicity registers, needs to be performed in the near future, based on the evidence obtained in this way. At the same time, health risk data will be useful for reducing the costs for reclamation and reuse, not using expensive treatments where they are not needed and using them where the risk is higher. There is then a positive impact due to a reduction in sanitary care derived from a reduced possibility of infections, work-time losses due to illnesses, and an improved quality of life.

Risk assessment can provide a statement of risk, but the risk manager still needs to decide what constitutes an adequate level of protection. Aside from quantifying the uncertainty impact in determining the level of protection provided in the final policy document, another way to use a risk value in setting public policy is to balance costs of additional regulation (treatment and monitoring) with the risk of infecting or affecting the human population, i.e., in a cost-benefit analysis.

Rather than relying simply on the benefits of averting a theoretical illness, a cost-benefit analysis views societal costs of illness and lost productivity as providing an economic gain. Meeting the objective of minimizing exposure to the risk of infection or toxicity may require a delicate balancing act in which microbial risk assessment (or the corresponding for toxicity) is used to weigh the benefits of changing wastewater reclamation policies. It is important to recognize that risk assessment is just one tool that aids the risk manager in establishing realistic water quality objectives [24].

Regulators are attempting to regulate to lower risk levels that are commensurate with lower pathogen or chemical pollutant concentrations. As one tries to increase removal or inactivation in order to obtain lower pathogen concentrations or fewer pollutant concentrations, the cost of treatment increases exponentially. Ideally, the risk manager must weigh social costs and benefits against the cost of increased regulation [24].

4. Conclusions

Reclaimed wastewater can be reused for different applications. Use-depending water quality categories were specified. For each category specific microbial and chemical limits are proposed and the analytical costs are assessed. To reduce the analytical effort, the parameters are graduated, the most important parameters being analyzed more frequently than less important parameters.

For setting guideline limits for reclaimed wastewater reuse, more microbial and chemical risk assessment is required. The microbiological parameters usually determined are insufficient or improper to perform a complete risk analysis. More data are needed for parasitic parameters and viruses. The list of chemical parameters in existing guidelines is either incomplete or excessive; therefore, it is necessary to find adequate indicators. This can be performed by quantitative chemical as well as quantitative microbial risk assessment.

References

[1] T. Mahin and O. Pancorbo, Wastewater pathogens. Water Environ. Technol., 11(4) (1999) 51–55.

[2] M. Salgot, C. Campos, B. Galofré and J.C. Tapias, Biological control tools for wastewater reclamation and reuse. A critical review. Water Sci. Technol., 43(10) (2001) 195–201.

[3] L. Pascual, Calidad microbiológica del aire en diferentes ambientes laborales: aplicación de métodos analíticos moleculares, PhD Thesis, University of Barcelona, 2001.

[4] C. Campos, Indicadores de contaminación fecal en la reutilización de agua residual regenerada en suelos, PhD Thesis, University of Barcelona, 1999.

[5] A.W. Olivieri, D.M. Eisenberg and R.C. Cooper, in: T. Asano, ed., City of San Diego Health Effects Study on Potable Water Reuse, Technomic, Lancaster, PA, 1998, pp. 521–580.

[6] C. Haas, J.B. Rose and C. Gerba, Quantitative Microbial Risk Assessment, Wiley, New York, 1999.

[7] WHO, Health guidelines for the use of wastewater in agriculture and aquaculture. WHO Tech. Rep. Ser. 778, Geneva, 1989.

[8] R.C. Cooper and A.W. Olivieri, in: T. Asano, ed., Infectious Disease Concerns in Wastewater Reuse, Technomic, Lancaster, PA, 1998, pp. 489–520.

[9] Italian Decree no. 185, Limits for wastewater reuse in Italy, 2003.

[10] Quality criteria for reuse of reclaimed wastewater for disposal to river bodies in Israel. Recommended Regulation, Israel, 2003.

[11] Quality criteria for reuse of reclaimed wastewater for unrestricted irrigation in Israel. Recommended Regulation, Israel, 2003.

[12] S. Weber, S. Khan and J. Hollender, Human risk assessment of organic contaminants in reclaimed wastewater used for irrigation, Desalination, 187 (2006) 53–64.

[13] A.C. Johnson and J.P. Sumpter, Removal of endocrine-disrupting chemicals in activated sludge treatment works. Environ. Sci. Technol., 35 (2001) 4697–4703.

[14] T.A. Ternes, Occurrence of drugs in German sewage treatment plants and rivers. Water Res., 32 (1998) 3245–3260.

[15] J.E. Harries, A. Janbakhsh, S. Jobling, P. Matthiessen, J.P. Sumpter and C.R. Tyler. Estrogenic potency of effluent from two sewage treatment works in the United Kingdom. Environ. Toxicol. Chem., 18 (1999) 932–937.

[16] K.L. Thorpe, R.I. Cummings, T.H. Hutchinson, M. Scholze, G. Brighty, J.P. Sumpter and C.R. Tyler, Relative potencies and combination effects of steroidal oestrogens in fish. Environ. Sci. Technol., 37 (2003) 1142–1149.

[17] T. Heberer, Occurrence, fate, and removal of pharmaceutical residues in the aquatic environment: a review of recent research data. Toxicol. Lett., 131 (2002) 5–17.

[18] J.E. Drewes, T. Heberer and K. Reddersen, Fate of pharmaceuticals during indirect potable reuse. Water Sci. Technol., 46 (2002) 73–80.

[19] M. Clara, B. Strenn and N. Kreuzinger, Carbamazepine as a possible anthropogenic marker in the aquatic environment: investigations on the behaviour of carbamazepine in wastewater treatment and during groundwater infiltration. Water Res., 38 (2004) 947–954.

[20] W. Körner, P. Spengler, U. Bolz, W. Schuller, V. Hanf and J.W. Metzger, Substances with estrogenic activity in effluents of sewage treatment plants in southwestern Germany. 2. Biological analysis. Environ. Toxicol. Chem., 20 (2001) 2142–2151.

[21] CEDEX, Propuesta de calidades mínimas exigidas para la reutilización directa de efluentes depurados según los distintos usos posibles, así como de aspectos relativos a la metodología, frecuencia de muestreo y criterios de cumplimiento de los análisis establecidos, para incluir en una normativa de carácter estatal, Spain, 1999.

[22] International Cooperation of Rhine Water Power, Water power specific guidelines for drinking water treatment close to nature. Industrial principle, Nieuwegein, 2003.

[23] D.R. Rowe and I.M. Abdel-Magid, Handbook of Wastewater Reclamation and Reuse, Lewis, Boca Raton, FL, 1995.

[24] T. Asano, Wastewater Reclamation and Reuse, Technomic, Lancaster, PA, 1998.