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Wastewater tertiary treatment options to match reuse standards in agriculture

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ABSTRACT

In Italy, the restrictive approach for reclaimed water (RW) use in agriculture has led to some difficulties in spreading this practice. In particular, matching microbiological standards, evaluated in terms of *Escherichia coli*, is quite prohibitive and highly intensive disinfection systems are the sole option to adequately treat municipal wastewater. A different view of the same concern is offered by the World Health Organization (WHO) that proposed a pragmatic approach, based on microbial risk assessment, to evaluate case by case the pathogen reduction in case of RW use in agriculture and how to achieve this.

In the study two different tertiary treatment options for RW use in agriculture were examined. The first option named “extensive tertiary treatment system – ETTS” included in series: horizontal sub-surface constructed wetland system, biological pond, storage reservoir, sand and disk filters. The second option named “hybrid tertiary treatment system – HTTS” included in series: horizontal sub-surface constructed wetland system, sand and disk filters, ultraviolet (UV) system.

Moreover, the microbial contamination on crop irrigated by RW from both examined systems was evaluated.

An economic analysis was carried out for a life cycle of 20 years of the treatment systems. Economic benefits and total cost of RW for agricultural irrigation using both the tertiary treatment options were evaluated.

Results evidenced that total costs of RW were similar for both options, anyway other benefits can support the choice of ETTS to treat RW for vegetable crop irrigation, especially for rural areas in developing countries.

1. Introduction

The Mediterranean region is one of the most vulnerable areas to climate change (Collet et al., 2015), and water shortages are expected to continue (La Jeunesse et al., 2016) due to the increasing degradation of water resources (overuse, pollution, salinization, etc.) and increasing water demand in agriculture as well as in the urban, industry, and energy sectors. As an effect of climate change, the frequency and intensity of droughts and their environmental and economic damages have drastically increased over the past thirty years. The droughts of the summer of 2017 may illustrate the dimensions of economic loss; the Italian farming sector alone was predicting losses of EUR 2 billion (EC, 2018). Agriculture is in fact the largest water user. The 2017 UN-World Water and Development Report (UNWWDR, 2017), based on FAO-Aquastat data states (FAO, 2016) that the water consumption for crop irrigation reaches 70%, on average, of the world water requirements (Ait-Mouheb et al., 2018).

When natural water reserves are not sufficient, one of the most available, constantly produced and relatively unaffected by climatic conditions water resource is the reclaimed water (RW) (EEA, 2009; Cirelli et al., 2012; Ait-Mouheb et al., 2018).

RW is already being used, directly or indirectly, in many semi-arid areas of the world (e.g. Africa, Central America, Southern Europe, Southern Asia) (Pedrero et al., 2010). In particular, RW is becoming an increasingly important source of irrigation being agriculture the highest water demanding user and often the most penalized among others. In Southern Europe, more than 50% of the total water consumption comes from agriculture (EEA, 2009). In Italy, in particular, in case of a lack of water, the water supply service often favours domestic and industrial sectors over the agricultural one, resulting in a negative impact on the local economy (Cirelli et al., 2012).

As RW can be an important source of water in agriculture (Barbagallo et al., 2012), its application should be regulated in order to prevent the use of water of insufficient quality that later can cause diseases to humans (Pedrero et al., 2010; Dickin et al., 2016). On the international level, the two benchmark guidelines for RW use are the California guideline (State of California, 1978) and the World Health Organization (WHO) guideline (WHO, 1989). The first one is stricter,

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following a ‘zero risk’ approach that adopts the ‘best available technology’ (US EPA, 2012; Seder and Abdel-Jabbar, 2011). The ‘zero risk’ approach is based upon the fact that pathogenic micro-organism could survive for days, weeks and at times months in the soil and on crops, so, detection in any of these environments is sufficient to indicate that a public health problem exists. Therefore, for example, recycled water used for the surface irrigation of food crops, where the recycled water comes into contact the edible portion of the crop, shall be disinfected tertiary recycled water. Instead, recycled water used for the surface irrigation of food crops, where the recycled water does not contact the edible portion, shall be at least a disinfected secondary recycled water (State of California, 2001).

For many years, the California state regulations were the only legal valid reference for recycling and reuse (Salgot et al., 2017).

WHO (1989), supported by a group of specialists, recognized that the extremely strict California standard for RW use, adopted by many countries was not justified by the available epidemiological evidence nor was it likely that many countries, especially developing countries, could meet this strict standard. The WHO guideline was more flexible and it was established in order to be applicable in developing countries with lower economic possibilities (Bixio et al., 2008). The WHO guidelines followed a ‘calculated risk’ approach, based on existing epidemiological evidence and they considered irrigation as an additional treatment stage. In particular, the WHO recommended a microbial guideline of not more than 1000 *Fecal Coliforms* (FCs) per 100 mL for unrestricted irrigation of all crops, with special emphasis on the removal of helminth eggs (no more than one egg per liter) during effluent treatment (Shuval et al., 1986; WHO, 1989). Then, World Health Organization (WHO, 2006) established a limit of *Escherichia coli* (*E.coli*) at 10^4 Colony Forming Units (CFU) per 100 mL for RW use on vegetables for consumption as fresh food. Afterwards, WHO, as well as Australian guidelines, recommended the implementation of a risk management plan including a risk assessment for water reuse systems. For this purpose, the WHO launched a Sanitation Safety Planning (SSP) manual as guidance on implementation of the WHO guidelines for water reuse (WHO, 2015).

Moreover, in order to reach an effluent quality suitable for irrigation, the California guideline proposed conventional biological treatments in combination with tertiary treatment, filtration and chlorine disinfection, while the WHO suggested a series of stabilization ponds (Barbagallo et al., 2003).

As consequence, there is fierce argument about the economics of RW use (Winpenny et al., 2010) and particularly on the practical consequences of decisions concerning effluent treatment levels. The differences between the two approaches and among the different guidelines and regulations, may raise doubts about their capability to protect end users; in particular, the countries that do not yet have guidelines or experience may decide not to deal with RW use (Brissaud, 2008; Qadir and Sato, 2016).

Most comprehensive standards developed specifically for RW use practices and issued by European States were, until today, either derived from the California guidelines (e.g., Greece, Cyprus and Italy) or from the Australian guidelines and revised WHO criteria (e.g., France) (WHO, 2014), or from a combination of the above (e.g. Spain and Portugal). Fawell et al. (2016) stated that the non-existence of the common standard is the biggest obstruction for the expansion of the RW use sector.

In Europe, a common strategy on RW use was issued on May 2018. In fact, based on the proposal of “Minimum quality requirements for water reuse in agricultural irrigation and aquifer recharge” (Alcade-Sanz and Gawlik, 2017), the European Parliament and of the Council has just proposed the European Directive on the “Regulation on minimum requirements for water reuse” (EC, 2018). This instrument is based on a risk management framework, which is recommended to tackle health and environmental risks and assure a safe use of RW for agriculture. The proposed directive could lead to water reuse in agricultural irrigation in the magnitude of 6,6 billion m^3 per year (as compared to 1,7 billion m^3 per year in the absence of any EU legal framework, EC, 2018).

Italian regulations for effluent irrigation in agriculture (Italian Ministry Decree 185/2003) follows the ‘zero risk’ approach. It fixes limits for 54 parameters 37% of which are not considered for drinking water analysis (Cirelli et al., 2008, 2012; Castorina et al., 2016). The high number of monitored parameters negatively affects to RW use (Angelakis and Gikas, 2014; BIO by Deloitte, 2015) and Italy is given as the extreme example of a country with a stringent monitoring protocol and severe limits but with only a small proportion of its RW used. This is in contrast to Israel, the country leader in RW use with less than a dozen parameters defined (Lavrnic et al., 2017).

Moreover, the limits fixed by the Italian regulations are very stringent for some of parameters such as BOD_5 ($< 20\,mg\,L^{-1}$), total suspended solids ($< 10\,mg\,L^{-1}$) and *Escherichia coli* (< 10 CFU $100\,mL^{-1}$ or < 50 CFU $100\,mL^{-1}$ for 80% of samples, respectively in the case of conventional treatment systems or treatment wetland and lagooning). The Italian approach is much more restrictive with respect to health hazards than the WHO regulations (e.g. WHO, 1989; Shuval, 1991; Peasey, 2000; Devaux et al., 2001; WHO, 2006; Cirelli et al., 2008; Aiello et al., 2013; Salgot et al., 2017).

The fulfillment of high limitations implies high-intensive treatments for the use of RW and consequently high costs, not always sustainable for users. The financial competitiveness of reuse projects compared to traditional water supply schemes is fundamental to support RW use (Frijns et al., 2016) especially in developing countries.

Conventionally, the comparison of RW use system alternatives is only based on economic data provided in the feasibility study of the projects, so that the alternative with minimum capital, operation and maintenance (O&M) costs is chosen (Zeng et al., 2007). Following the Sustainable Sanitation Alliance (Andersson et al., 2016; SuSanA, 2018), it is key to implement sanitation systems which are sustainable. In order to be sustainable a sanitation system has to be not only economically viable, socially acceptable, and technically and institutionally appropriate, it should also protect the environment and the natural resources. The latter involves the required energy, water and other natural resources for construction as well as O&M of the system.

Constructed Wetland (CW_s) are among the wastewater treatment systems more environmentally sustainable, involving the use of engineered technologies that are designed and realized to utilize natural processes. These systems are designed to mimic natural wetland systems, utilizing wetland plants, soil, and associated microorganisms to remove contaminants from RW effluents (US EPA, 2012). CW_s can be adopted as a tertiary-treatment technology due to their low O&M costs and efficiency in treating RW from small and medium communities. CW_s are used for treating various wastewater types and for polishing advanced treated water effluents for return to freshwater resources (US EPA 2012; Toscano et al., 2009). CW_s have been suggested as alternative for treating nitrate contaminated aquifers, denitrification of nitrified sewage effluents and irrigation return flow (Baker, 1998; Mara, 2013). Moreover, CW_s treated municipal effluent directed to irrigation may contain readily absorbable useful nutrients and easily biodegradable organics. These substances are generally compatible with the limits imposed by the Italian regulations (M.D. 152/2006) for treated water discharged in water bodies (Cirelli et al., 2012; Castorina et al., 2016).

In order to give a contribution to the argument on the ‘zero risk’ and ‘calculated risk’ currently followed worldwide, in this paper a removal efficiency (in terms of both physical-chemical and microbial) analysis of two different tertiary treatment options for RW use in agriculture was carried out. To evaluate a feasible reuse alternative, a quantitative economic analysis was performed for both treatment options at full-scale of application.